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PRODUCT ENGINEERING

APRIL, 1939

REFERENCE AND DIRECTORY NUMBER

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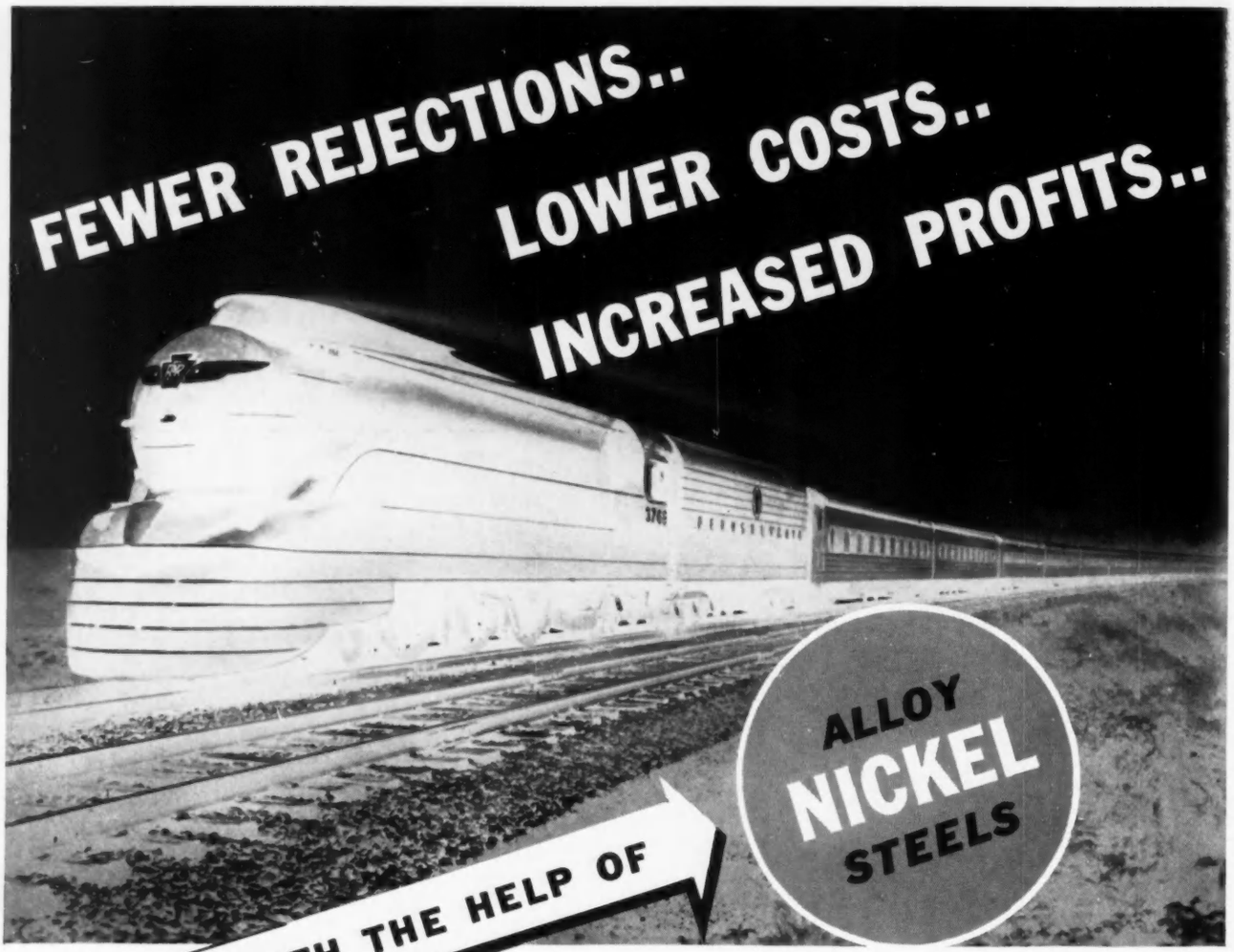

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PRODUCT ENGINEERING

What's Coming—In March *P.E.* was shown the "Machine That Spins, Processes, Dries and Twists Viscose Rayon Continuously." The outstanding features of that machine were briefly described by pictures and captions, but the story of its development is undoubtedly more significant and more inspiring than even the machine itself. With the cooperation of the officials of the Rayon Machinery Corporation and the assistance of R. F. Bergmann, its chief engineer we have been able to get the whole story of this amazing development from the time of its conception to the final product. It will be the feature article of the May number.

Shrinkage stresses in welded joints, fibrous glass insulation, multi-speed motors, and electrical contact materials are among the other articles for May *P.E.*

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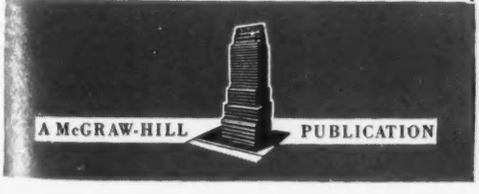

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"Dat dere ain't no *ordnary* mule!"

You'll remember that's what Mose said when someone asked him what good his relaxed and droopy-eyed mule was. And how he explained, "He jes unlaxes like dat 'til we works 'im—den dere jes ain't no mule dat kin match his git."

And that's the way we feel about this Reference and Directory Number. It looks pretty much like other issues of Product Engineering until you've really put it to work. After that, we know you'll agree that it has no equal.

★ ★ ★

How to Make This Issue Work for You

In the editorial section, you'll find over 30 pages of "high-reference" material on over a dozen different subjects. It's all written in a concise, informative style for easy use time and again during the year.

The separate Directory section, printed on special buff-colored paper, carries thousands of up-to-date listings classifying sources of supply for parts, materials, and finishes. Remember, this specialized and authoritative Directory contains only those headings in which you, as a product engineer, will be interested. It includes items that you specify for the many kinds of mechanical products you are called on to design . . . as well as engineering-department equipment and supplies.

As in every issue, there are hundreds of advertisements addressed specifically to you. Many of these are "tied-in" with the reference and directory idea of this number, and listings of all advertisers in this issue appear in the Directory in bold-face type. It will pay you to refer to their advertisements.

Make this reference issue an active part of your working library

PROMINENT PRODUCT ENGINEERS HAVE FOUND IT PAYS TO READ THE ADVERTISING IN PRODUCT ENGINEERING

PRODUCT ENGINEERING

APRIL, 1939 GEORGE F. NORDENHOLT, *Editor* VOLUME TEN, NUMBER FOUR

The Basis of Comparison Is Experience

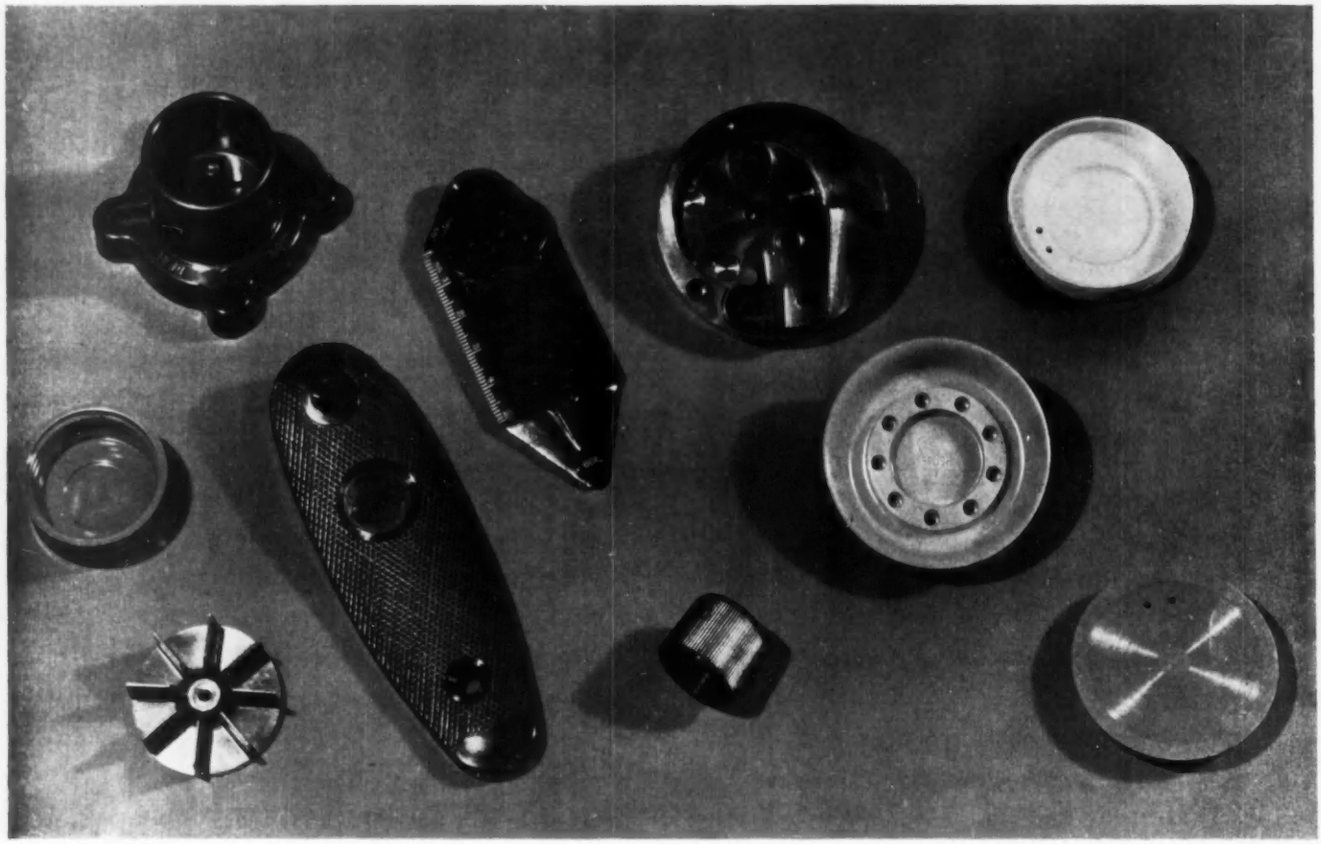
QUOTING Lord Kelvin, "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be."

To measure something is "to compute or ascertain the extent, degree, quantity, dimensions, or capacity of that thing, by a rule or standard; hence to estimate; value; appraise." Even to scientists and engineers numbers of units of measurement often in themselves only symbolically represent to the mind something which may not be immediately perceived. An ultimate tensile strength of 200,000 lb. per sq. in. in itself means nothing. It does not give a mental appraisal of the strength value of the material having that property until the mind compares that measurement with the corresponding measurement for another material with which the mind is familiar. Thus, if one knows that the familiar plain carbon steel has an ultimate strength in tension of 60,000 lb. per sq. in. whereas the other material has a corresponding strength of 200,000 lb. per sq. in., the mind immediately senses that the material has 3-1/3 times the strength of plain carbon structural steel. A sound level of 100 decibels means nothing until one knows that in a quiet office the sound level is about 35 decibels and that 15 decibels is the measure of a whisper.

The accepted systems of measurements that we have were devised solely for the purpose of making comparisons. Through experience and by storing facts and figures in the mind, a person accumulates a kind of knowledge which enables him to pass sound judgment upon apparently complex problems. He is able to do so because he has established in his mind a keen sense of relative values.

Both physical experiences and factual data are necessary if one is to be able to make sound decisions. The "impractical" man is impractical because he lacks the physical experiences. A deaf man cannot pass judgment on problems of sound nor can a blind man solve problems of light.

Physical experiences can be obtained only by activities and observations. Factual data can be found in the literature of the art. With this latter in mind, we have devoted this number of *Product Engineering* entirely to the presentation of factual information, including both data and methods. Not all of the things we have presented can be measured in standard units. But experience will serve as the basis upon which to judge relative values of the different methods presented for the solution of problems. After all, measurement is solely for the purpose of comparison.



AUTOMATIC PLASTIC MOLDING

Data and information furnished by F. J. Stokes Machine Company

WITH FULL AUTOMATIC presses now available the art of plastic molding, aided by the developments in plastic molding materials, becomes less dependent upon skilled operators and consequently unit costs are largely determined by the initial investment in molds, the cost of the material selected and cost of power for operation.

Usually, by taking some forethought the designer can reduce mold costs by designing the single-cavity hand mold, ordinarily made up for production and acceptance studies, for later adaptation and installation in the automatic molding machine.

Since it is not unusual to operate automatic molding machines continuously 7 days or 168 hours per week, it is possible to make a lot of a few thousand pieces with an automatic press and a single-cavity mold before a multiple cavity mold could be completed. Further on this basis of operation, if a single-cavity mold can be made in two weeks and if it would take four weeks to make a 12-cavity semi-automatic mold for the same piece, more than 32,000 molded pieces could be made on an automatic press with a 1½ min. cycle running 168 hr. per week before the 12-cavity mold with a 2½ min. cycle running 40 hr. per week could produce the same number.

Thermo-setting or thermo-plastic materials can be handled in the automatic molding machine. Granular or powdered molding material is loaded into the hopper of the machine, from which a charge measured by a micrometer volume metering device is fed by gravity through tubes to the cavity or cavities of the open mold.

Loading the storage hopper with new material, carrying the finished parts to a tumbling barrel, loading and unloading the barrel are the only operations requiring labor after the machine has been set up for production, since after molding and ejection the piece is lifted free of the mold by a blast of air from a jet and falls into a chute leading to a catch box.

Filling the mold with a definite volume of material, closing the mold and the press, de-gassing or breathing, applying a predetermined pressure, controlling the mold temperature, timing the cure, opening the press and mold, ejecting the molded part and blowing it into a discharge chute, and starting a new cycle, all these operations are performed automatically without loss of time between operations in the automatic molding press.

Because the amount of material that is charged into the molds is accurately measured, the mold can be designed with flash that is paper thin, so thin that it can often be removed in assembling operations thus eliminating punching, shearing, drilling and grinding for flash removal. The material that is ordinarily wasted in flash is considerably reduced with this system of measuring the charge and, of course, the value of the amount so saved is in proportion to the unit cost of the material.

Uniform physical properties and dimensions of the molded part are assured since the time and temperature of the cure, as well as the molding pressure are maintained constant for all pieces made in the single cavity. Uniformity in dimensions may be an important factor if the molded piece is later assembled with other parts.

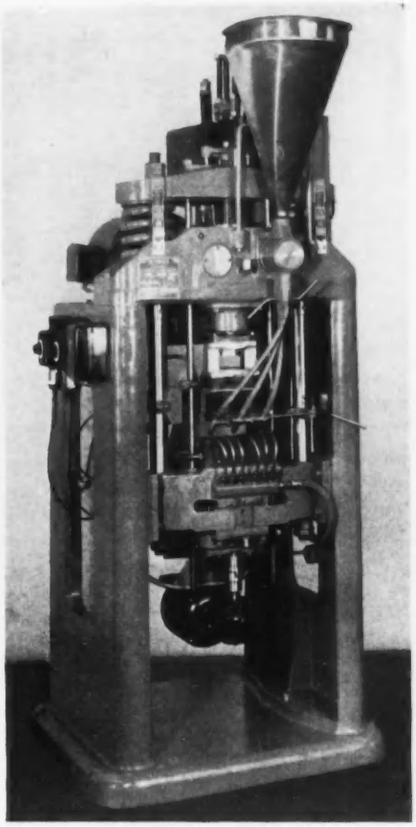


Fig. 1—Fully automatic motor driven plastic molding press in which all operations are electrically timed and controlled

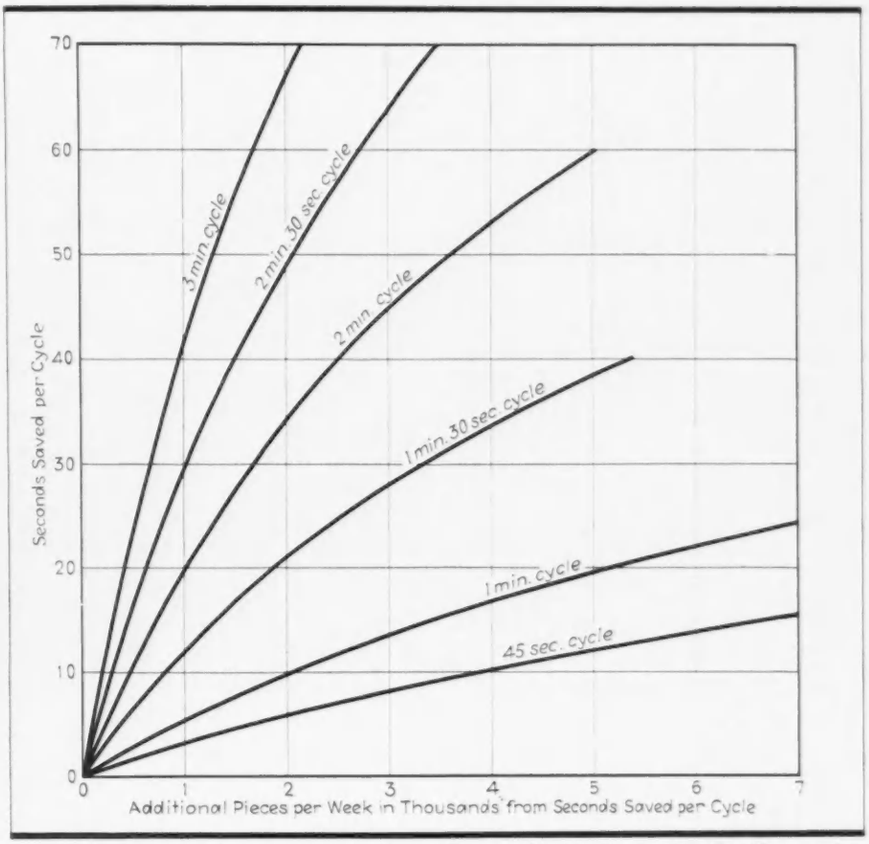
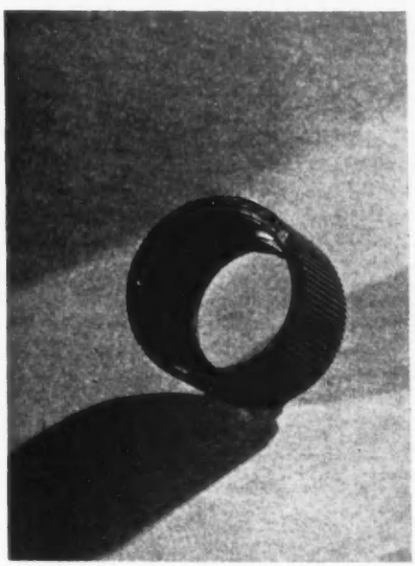
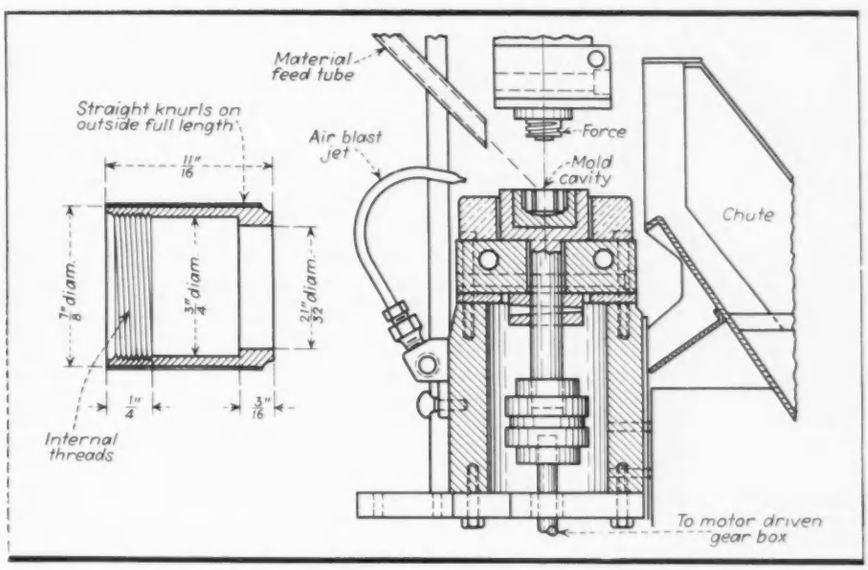


Fig. 2—Importance of saving seconds in molding cycle time is graphically illustrated by chart. Curves show additional pieces that can be molded per 168 hr. week by cutting seconds off the time of various molding cycles





Internally threaded piece molded and unthreaded three at a time, operations are completely automatic. The press used is provided with a three-compartment powder-measuring device and three separate cavities each equipped with an unscrewing device to remove molded pieces from the threaded forces. The outside surface of molded part is fluted or grooved axially so that as mold is rotated by the stripping motor the molded part also rotates and screws off the force. The force moving upward also carries the piece upward in the mold during the unthreading operation which is completed just as the piece is free of the cavity. The piece is then blown with an air jet into the chute. The unscrewing device is automatically timed to synchronize with other press operations.

This part is an excellent example of how seconds saved in the molding cycle is reflected in costs. Data taken from a cost study on 3,000 of these parts made of a phenolic plastic material show that at 12 cts. per lb. the material cost $2.61, the cost of power for operating and curing was 23 cts. with a rate of 1.5 cts. per k.w.h., and the production time for 3,000 pieces was 12.5 hr. The molding time per cycle was 45 sec., which includes 27 sec. for curing. Three single-cavity flash type molds were used in the press. Weight of piece is 3.1 grams. Total cost per piece is less than 1/10 ct. not including overhead and finishing.

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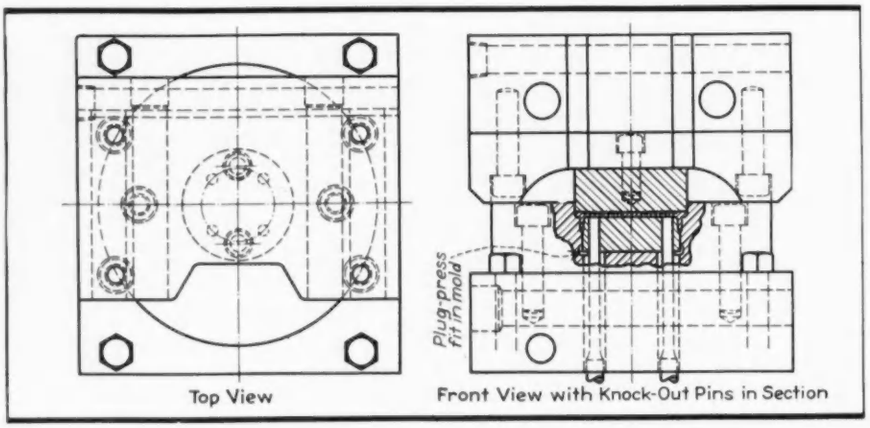
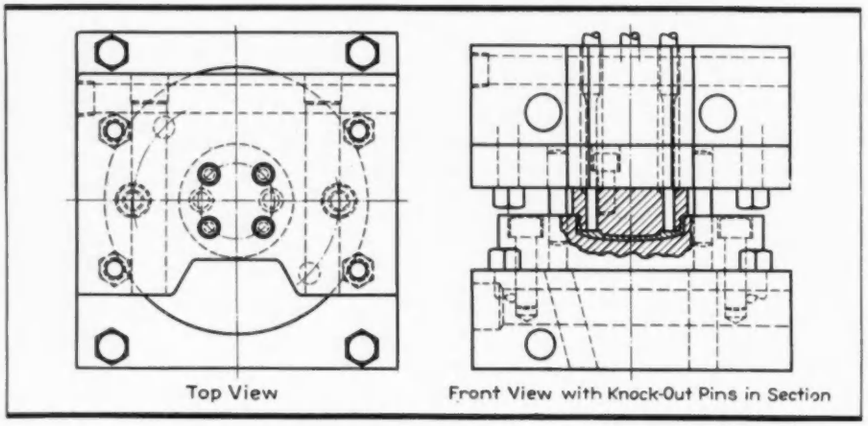


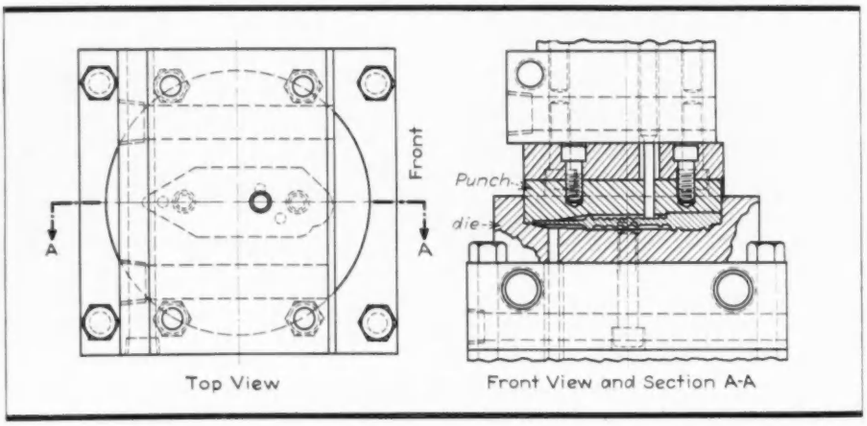
Box bottom. Knock-out pins should be located in the mold so as not to interfere with filling the mold with powder; they should be at 45 or 90 deg. to feed line. Pins in top and bottom of the mold should never be on the same center because of the possibility of jamming each other when adjusting the ejector pin positions when setting up the mold in the press. Pilot pins are desirable although none are shown in the sketch of the mold.

Cost study data per thousand using a phenolic compound are as follows: Cost of material at 16 cts. per lb. is $2.61, the cost of power at a rate of 1.5 cts. per k.w.h. is 26 cts., the production time per thousand is 16.7 hrs. The molding time per cycle is 60 sec. of which 7 sec. is for preheating, 4 sec. is for breathing and 29 sec. is for curing. The mold used is shown in the illustration above. Weight of the finished piece is 7 grams. Total cost per piece is less than 3/10 ct. not including overhead and finishing.



Box Lid. Annular bead on force lifts piece from mold and ejector pins in force snap piece off the force. This method of stripping is sometimes used when the bottom of the mold forms a surface that would be marred by knock-out pins. Another method of accomplishing the same result is to make the force with a slight increasing taper so that molded section is undercut to lift piece from the mold.

Cost study data per thousand using a urea formaldehyde compound are as follows: Cost of material at 32 cts. per lb. is $6.91, the cost of power at a rate of 1.5 ct. per k.w.h. is 37 cts., the production time per thousand is 20.6 hr. The molding time per cycle is 1 min. 14 sec. of which 56 sec. is for curing. Weight of the finished piece is 9.3 grams. Total cost per piece is less than 7/10 ct. not including overhead and finishing.



Straight thin pieces can be molded satisfactorily in molds of the sub-cavity or semi-positive type with a land along all thin sections to form sub-cavity to prevent the piece bending and warping. Knock-out pins should be placed so that they lift the piece out of the mold level. Pilot pins are desirable, although none are shown in the sketch of the mold. to keep force and mold in alignment. Outside lands are unnecessary when the sub-cavity type of construction is used.

INDUSTRIAL ADHESIVES

JOHN L. PERKINS, *RESEARCH ENGINEER, B. B. CHEMICAL COMPANY*

THERE IS scarcely a manufacturing concern today that has not some sort of an adhesive problem essential to its production processes or products. Whereas in the past these perplexing problems were often cast to one side as impossible, they now can be solved readily and satisfactorily because many new and diversified adhesives have been developed for the manufacture of industrial equipment and the fabrication of products for consumers' use.

Many manufacturers are still using methods of assembly or construction which they could now replace by using adhesives, perhaps because they are not aware of the fact that the adhesive required is now available. Or perhaps the idea has never been suggested to them to modernize their mode of manufacture by utilizing these new cements. Manufacturers who have changed their processes by adopting the use of industrial adhesives have found it to their advantage in such vital factors as increased speed of production, decreased labor cost, less machinery, smaller floor space requirements, and less capital investment.

Industrial adhesives are being used extensively by a wide range of industries, including the aircraft industry where exacting requirements have to be met. Automobile manufacture is another specialized industry requiring certain types of adhesives. Cable manufacture has to have a cement which tightly bonds the insulation cover to the metal wire. Laminated sound and heat insulation board coverings are firmly constructed by bonding materials. The printing industry utilizes rubber covered steel rolls, which necessitates the firm bonding of rubber to steel; and metal rolls are covered with sponge rubber for the paper, tannery and other industries. The manufacture of women's vanity cases requires another type of cement. In the construction of baseballs and other sport goods, various cements are used. Plastic covered table and chair construction requires another adhesive. Musical instrument manufacturers use adhesives for assembling instruments. The construction of oil resisting hose utilizes another type of adhesive.

The question of industrial adhesives is a complex one and the manufacturer is constantly faced with new problems. It would be unwise to classify industrial adhesives by their specific applications because many of them can be utilized in some field entirely foreign to their original purpose. Then too, the difficulty of drawing valid classification is further complicated by the ever varying requirements of different cementing problems. For example, there are many factors such as heat, chemical, oil, sunlight, and abrasion resistance, resiliency, and cold flow to be considered. All of the above properties are indefinite, and it is impossible to say how a particular adhesive will age unless the conditions of usage are known. For instance, heat resistance is a vague term that requires definition before exact recommendations can be made for a certain type of adhesive. For such reasons, before an adhesive can be properly chosen a complete knowledge of the characteristics of the materials to be cemented, the purpose of the bond, and the usage must be known.

Cemented assemblies wherein the parts are held together by adhesives, may seem strange to some mechanical designers. But this method of assembly or construction is now being used extensively. Its use has been made possible by the availability of many new types of adhesives. Pioneered in the furniture, shoe and rubber goods industries, cemented assemblies are now widely used in such diverse products as airplanes, electrical equipment, automobiles, ships, printing presses and novelties.

One important industrial group of adhesives can be divided into the following types:

1—Air-drying solvent adhesive compounds containing rubber
2. Air-drying solvent rubber adhesives
3. Air-drying latex adhesives

RUBBER-TYPE ADHESIVE COMPOUNDS are manufactured for different kinds of uses with various viscosities that range from brushing to putty consistence. They give exceptionally strong adhesion, are waterproof, are non-staining, and are permanently resilient. These rubber-compound adhesives fulfill many cementing problems in industry, and are of immediate interest to many fields of engineering. At present they are used where adhesion to metals, celluloid, rubber, brickwork, stone, wood, plastics, glass, plaster, felt insulation and leather is desired.

Other fields of use for this type of adhesive are found in automotive, aircraft and shipbuilding industries. In these, they are used for attaching running board coverings, and cork or composition strips to airplane wings for wing-walks, for attaching sheet insulations to airplane interiors, and for watertighting glass and plastic windshields, portholes and side windows.

AIR-DRYING SOLVENT RUBBER ADHESIVES are widely employed in many fields of manufacture. In the production of shoes, these rubber cements are used for cementing channels, sole counters, insoles, and heel coverings. They are also used for upholstery work in automobiles and airplanes. Other applications include pocketbooks, photo-mounting, bookbinding, raincoat manufacture, and attaching protective coatings to highly polished metal surfaces.

LATEX-TYPE RUBBER ADHESIVES consist of an aqueous suspension or dispersion of extremely small rubber particles. This type of rubber adhesive as compared with the solvent rubber cement has certain advantages such as non-inflammability, inherently greater film strength, absence of stringing when sprayed, and greater coverage because of the higher rubber solids. Latex adhesives are utilized equally as much in the shoe industry as solvent rubber cements. Additional uses include the lamination of paper and the bonding of materials, such as cork, fabrics, rubber, fibreboard and hair bristles in brushes.

A second industrial group includes some recently developed adhesives which have many technical applications. These cements can be sub-divided into the following classes:

1. Chloroprene adhesive
2. Thermosetting chlorinated rubber and chloroprene combination
3. Thermosetting cyclized rubber-chloroprene adhesive

CHLOROPRENE ADHESIVE has the desirable property of withstanding the dete-

riorating action of oils, gasoline and other solvents, in addition to its superiority to rubber adhesives in natural aging, sunlight resistance and tensile strength. These advantages make it specially suitable for bonding leather to leather, rubber to leather, rubber-like synthetic products to other materials; also for many other purposes such as oil resistant protective coatings, water-proof and gas-proof gaskets for riveted seams in airplane construction.

THERMOSETTING CHLORINATED RUBBER AND CHLOROPRENE combinations are recommended for bonding with heat, at 130–140 deg. C., synthetic rubber-like materials such as chloroprene, butadiene and alkylene polysulphide polymers to metals. With this combination of a chlorinated rubber primer applied on the metal and then on top of it a chloroprene tie-cement, it is now possible to utilize these rubber-like materials to the greatest advantage. Some of the technical applications include the manufacture of composite products such as molded chloroprene parts with metal inserts bonded strongly into them, the attachment of oil resisting cable sheaths to wire cables and the bonding of chloroprene to metal for absorbing vibrations, deadening noise and electrical insulation.

THERMOSETTING CYCLIZED RUBBER-CHLOROPRENE ADHESIVE is used with heat cure for bonding rubber to metals and various types of alkylene polysulphide polymers to other materials. The applications are similar to those of the second group such as bonding rubber linings to steel tank interiors.

CELLULOSE ESTER ADHESIVES are a third industrial type which has a wide range of applications. Part of the reason for the adoption of this type is its excellent adhesion and inherent waterproofness, oil resistance and low cost.

One of the largest applications of cellulose adhesives is found in the shoe industry which uses pyroxylin cements for sole attaching as an alternative to the time honored stitching method. Shoes made in this manner are equally durable, and cheaper to manufacture. In 1938 ninety million pairs were made in this fashion.

There is no doubt that the future will see a steadily increasing application of industrial adhesives and in keeping with the modern trend toward the development of new materials, new machines, and the streamlining of industry with carefully controlled processes, many new adhesives will be developed.

Ordinary pastes, glues and thermoplastic adhesives which require high working temperatures and pressures have been excluded from this article because they have relatively few industrial applications.

INDUSTRIAL ADHESIVES AND APPLICATIONS

TYPE	NATURE OF CEMENT	ADHERES TO:	TYPICAL INDUSTRIAL APPLICATIONS
Rubber Type A	Air-drying compounded rubber base solvent cement	Metals Rubber Wood Glass Plastics Stone Fabrics Cork Asbestos sheets	Plastic, metal and linoleum covered tables Metal letters to glass, wood, etc. Clock construction Typewriter sound deadening Bonding anti-drumming materials Bonding mirrors in vanity cases Attaching handles to cardboard cartons Furniture construction Aircraft and auto sound insulation Foil lacquered labels to cellophane
Rubber Type B	Air-drying rubber solvent cement	Rubber Leather Rubberized fabrics Wood Cloth Paper	Sports goods Felt insulation to metal, wood, etc. Cardboard box construction Automobile and aircraft Upholstering adhesive Blueprint adhesive General household adhesive Photo-mounting Attaching protective coatings to highly polished metal surfaces
Rubber Type C	Air-drying aqueous suspension of rubber	Leather Rubber Fabrics Paper Wood	Label adhesive Airplane and automobile upholstery Suit case construction Cardboard containers Rubber sheeting to wood and plaster board
Chloroprene self vulcanizing	Air-drying rubber-like synthetic cement	Leather Rubber Rubber-like synthetic materials Cloth	Seaming coated fabrics Cable sheaths insulation Gasoline proofing riveted metal seams Butt-jointing rubber and rubber-like synthetic materials Bonding oil and gasoline resistant linings to outer sheaths, or to frictioned fabric Seaming garments and aprons for oil-field use Seaming fabrics for gas-bag
Thermosetting chlorinated rubber-chloroprene combination	Air-drying rubber-like synthetic cements	Rubber Metal Synthetic rubber-like materials Fabrics Braid	Bonding synthetic rubber-like materials to metal cable-armor Rubber covered steel roll Bonding metal inserts to rubber and rubber-like synthetic materials Bonding resilient covering to steel keg and other containers Bonding steel and aluminum nipples and couplings to hose without mechanical attachment
Thermosetting cyclized rubber-chloroprene combination	Air-drying rubber-like synthetic cements	Rubber Metals Synthetic rubber-like materials Fabrics Braid	Bonding rubber to metal Bonding synthetic rubber-like material to fabric or braid Bonding rubber to synthetic rubber-like materials Bonding certain synthetic rubber-like oil resisting materials to the same material
Cellulose Ester	Air-drying solvent nitrocellulose cement	Leather Metals Cloth Wood Rubber	General office adhesives Toy and novelty construction Furniture construction

VIBRATION ISOLATION

THE ABILITY of the commonly-used materials—metals (in the form of springs), rubber, cork, felt, rubberized fabric or felt—to satisfy the isolation requirements of many different jobs depends entirely upon their elastic characteristics. When the materials possess no damping properties the formula for free spring absorption applies. The values for this formula are plotted on the logarithmic chart below. Experiment has shown that the ratio of impressed frequency to natural frequency of the spring and mass must be about four to one for 93 per cent effectiveness. When this ratio drops as low as two to one the effectiveness drops to about 56 per cent. The impressed frequency for various isolation ratios is included on the chart below for convenience.

Change in materials will not affect the diagram given below as far as the fundamentals are concerned. However, since each material deflects differently and has different resilient characteristics under load, some measure of load per unit area and unit deflection must be available.

Factors which should be known in order to effect the solution of the problem are: capacity, speed and weight of the machine; accelerating and free forces of reciprocation or rotation; irregularity of motion; range of force frequencies of operations; natural frequency of sub-soil, floor or foundation.

Relative effects of damping are shown on the graph, next page. For example, with a damping co-efficient of 0.4 the isolation effectiveness drops from 83 down to 75 per cent at an isolation ratio of 2.5. Whether or not this is serious depends on the type of installation and the stresses involved. If it is serious and larger deflections are not important, the installation can be given more freedom thus raising the isolation ratio. In this case a ratio of 3.25 for the damping material would give 83 per cent effectiveness.

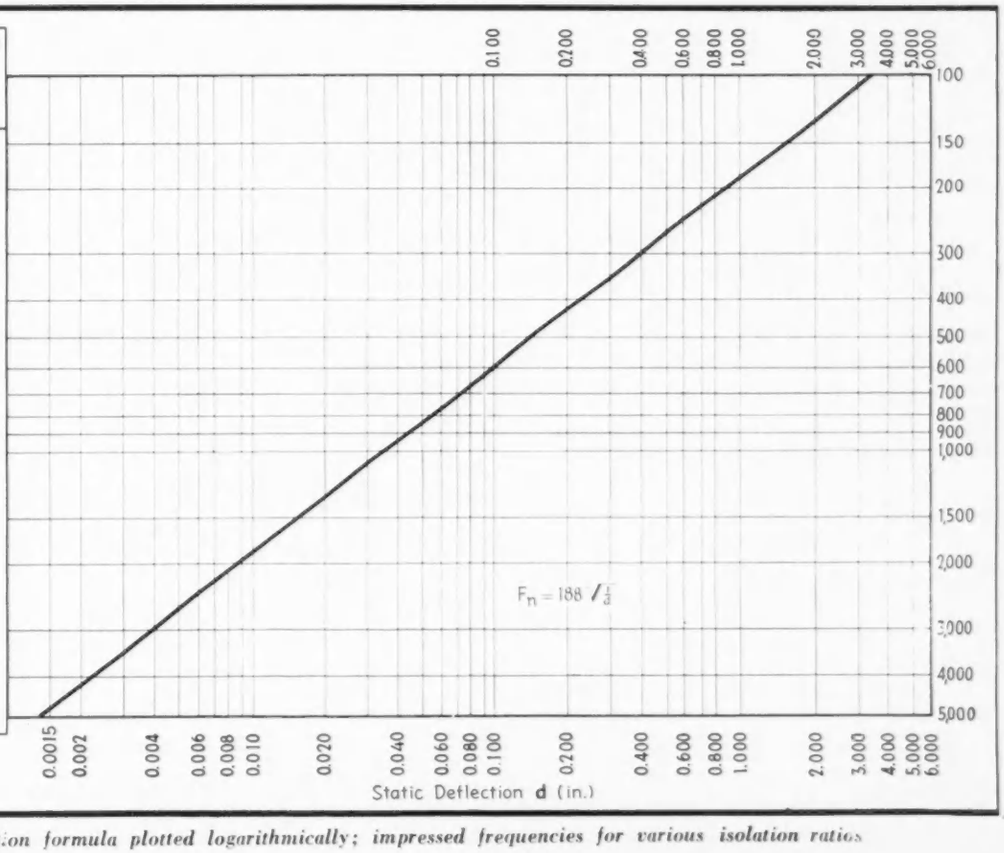
Valued assistance in the preparation of this article was rendered by the Felters Company, the B. F. Goodrich Company, Goodyear Tire and Rubber Company, Korfund Company, Lord Manufacturing Company, Sponge Rubber Products Company, United States Rubber Company, Vibration Eliminator Company, and Western Felt Works.

There is considerable overlap in the field of application of the various materials. S. Rosenzweig in his paper, "Theory of Vibration Control" (A.S.M.E. meeting, Dallas, Texas, June 7, 1938), shows that in compression 3-in. thicknesses of cork are satisfactory for natural frequencies down to 670 cycles per min., 4½-in. thicknesses down to 550, 6-in. thicknesses down to 470, and 8-in. thicknesses down to 420 cycles per min. A 6-in. thickness of rubber is satisfactory in compression down to natural frequency of 170 cycles per min., while steel springs can be adjusted to lower natural frequencies.

The chief characteristics of the principal isolation materials are briefed below:

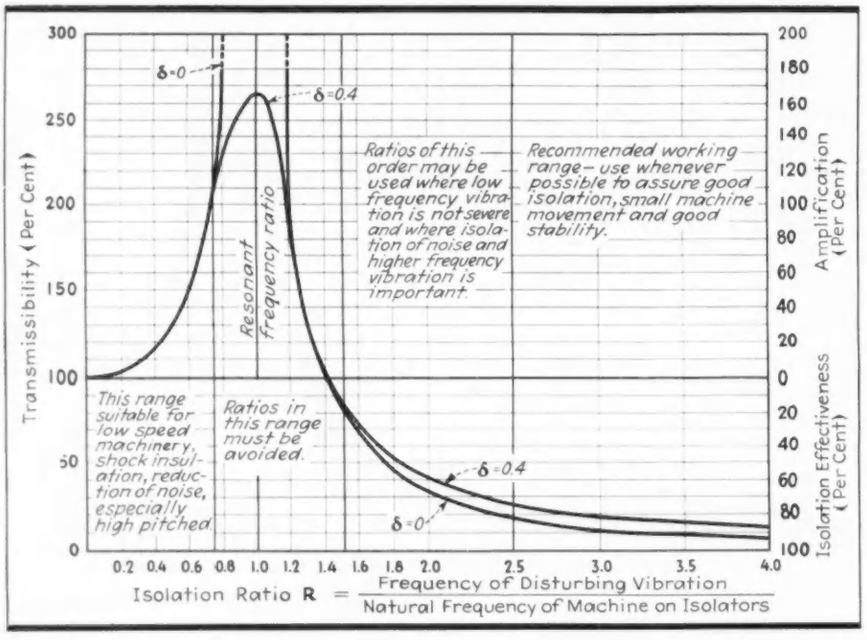
CORK. Used in compression, occasionally in combined shear and compression, cork deflects less per unit load than either steel springs or rubber. Cork has good resiliency characteristics within a limited deflection range and is not affected by oils, water or temperature. Standard mountings are available for use directly under a machine, or the felt can be used in pads under concrete or steel bases. Recommended loadings vary from 500–3,000 lb. per sq. ft. on 3-in. thickness and from 1,000–3,000 lb. per sq. ft. on a 1½

Impressed Frequency F_f (cycles per min.)				Normal Freq. F_n
Isolation Ratio F_f / F_n				
4.0	3.0	2.5	2.0	
600	450	375	300	150
800	600	500	400	200
1,200	900	750	600	300
1,600	1,200	1,000	800	400
2,000	1,500	1,250	1,000	500
2,400	1,800	1,500	1,200	600
2,800	2,100	1,750	1,400	700
3,200	2,400	2,000	1,600	800
3,600	2,700	2,250	1,800	900
4,000	3,000	2,500	2,000	1,000
6,000	4,500	3,750	3,000	1,500
8,000	6,000	5,000	4,000	2,000
12,000	9,000	7,500	6,000	3,000
16,000	12,000	10,000	8,000	4,000
20,000	15,000	12,500	10,000	5,000
Per Cent Isolation Effectiveness				
93.0	87.5	81.0	66.6	



Free spring absorption formula plotted logarithmically; impressed frequencies for various isolation ratios

VIBRATION ISOLATION


Transmissibility (Per Cent)
Amplification (Per Cent)
Isolation Effectiveness (Per Cent)
δ=0
δ=0.4
Resonant frequency ratio
Ratios of this order may be used where low frequency vibration is not severe and where isolation of noise and higher frequency vibration is important.
Recommended working range—use whenever possible to assure good isolation, small machine movement and good stability.
This range suitable for low speed machinery, shock insulation, reduction of noise, especially high pitched
Ratios in this range must be avoided.
Isolation Ratio R = Frequency of Disturbing Vibration / Natural Frequency of Machine on Isolators

in. thickness. The thicker plates are used for severe vertical impact loads. Cork is also effective for reducing amplitude of motion at resonance point.

FELT. Has good deflection characteristics particularly in large thicknesses. It is used in compression in the form of pads under concrete or steel sub-bases or directly under machine bases for loads up to 350 lb. per sq. in. For thicknesses of ½ to 1 in., loadings of 10–50 lb. per sq. in. are satisfactory. Felts, in general, possess a high damping coefficient which makes them effective at resonance, see Fig. 2, thus in many commercial applications eliminating need for auxiliary devices. Felt is sound-absorbing and is not affected by water, petroleum products, dust or other deteriorating conditions, but it is attacked by strong acids and alkalis. Felt is often used in combination with spring mountings for heavy industrial equipment.

METAL SPRINGS. Deflection can be varied as required for most effective isolation ratio by controlling spring dimensions, material and heat-treatment. Springs are satisfactory for low-frequency periodic vibrations and possess practically no damping. Leaf springs have less deflection and therefore less effectiveness for low frequencies, but leaf friction may provide some damping. Springs are not affected by atmospheric conditions or by high operating temperatures. Noise can be minimized by setting the springs on felt, rubber pads or similar insulating material.

RUBBER. Provides the greatest deflection per unit load of all materials listed here, excepting steel springs; thus it is particularly effective at low loads. As load increases, the deflection curve changes from a straight line characteristic; maximum loads in tension, torsion or shear should be 40–70 lb. per sq. in., maximum deflection about 70–80 per cent. Rubber stressed in compression carries heavier loads for a smaller deflection than rubber stressed in shear. The mechanics of installation can be calculated as closely as for springs. Rubber has a low sound conductivity coefficient, resists chemical and abrasive action, but is not generally recommended for continued exposure to temperatures over 125–150 deg. F. because of the tendency of the rubber to creep. In special high temperature installations, a lower unit load should be used. Since rubber is a chemical compound, characteristics will vary with analysis and processing, hence it is advisable to consult the manufacturer for definite recommendations on loading and application.

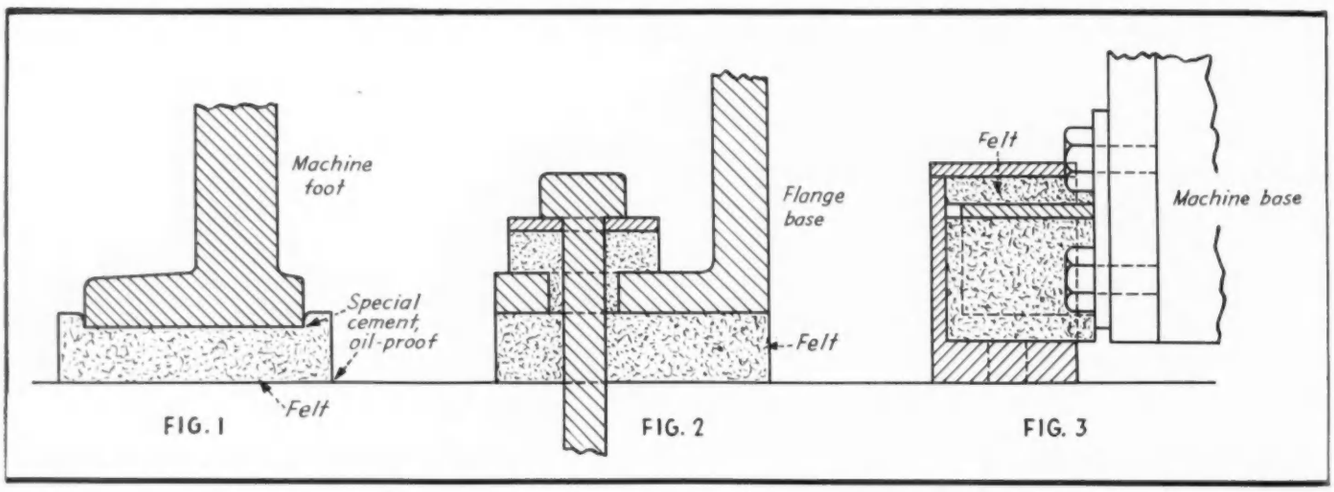
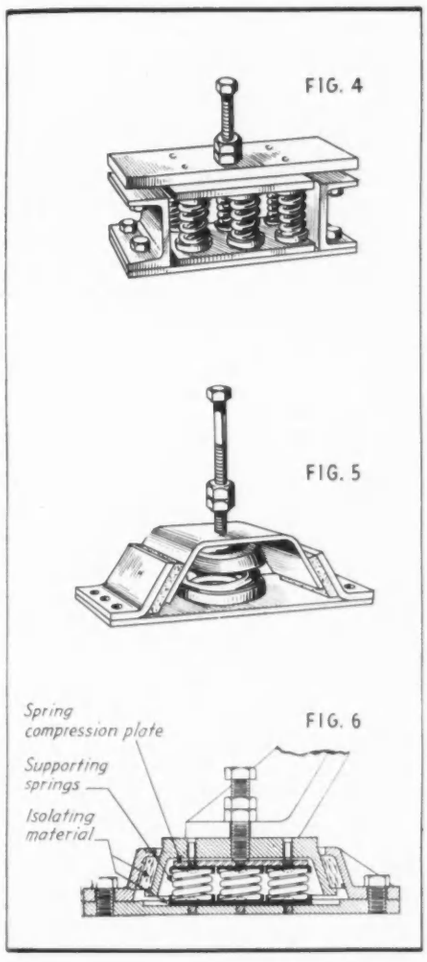


FIG. 1 FIG. 2 FIG. 3

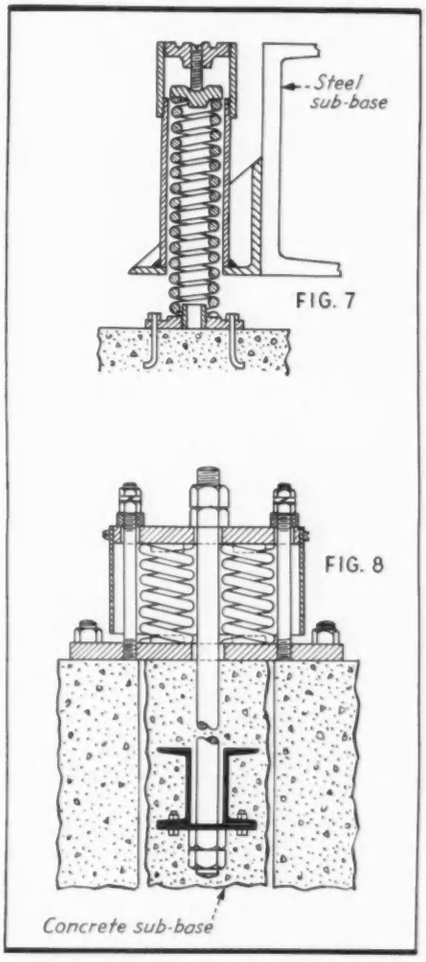
Felt pads cemented to base of the machine and to supporting member, illustrated in Fig. 1, simplify installation by eliminating hold-down bolts. When horizontal motions exist, the felt absorbs the forces which in a rigid setup cause bolt-shearing action. Pads are cut slightly larger to allow foot of machine to bed itself as shown. Proper solvent will loosen cement to allow for machine changes.

Conventional method of preventing "bridging," illustrated in Fig. 2, includes isolation of bolts with felt. Load exerted by bolt is a factor in choice of felt type.

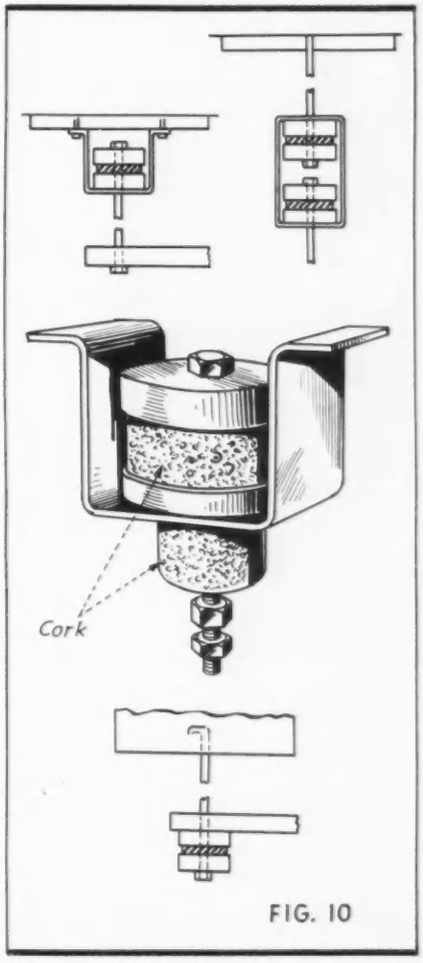
When use of cement or through bolts is impractical, various forms of housings may be provided. Type shown in Fig. 3 has no through fastening; machine is held against thrust in any direction when units are in opposing positions.



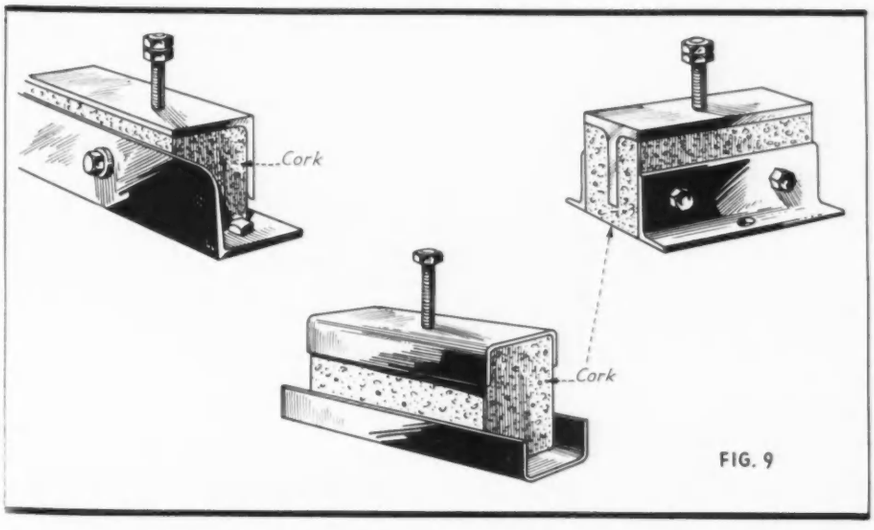
Spring-type isolators having one to nine springs of varying lengths and sizes provide load capacities of 50 to 12,000 lb. Characteristics can be adjusted before or after installation. These are applied to punch presses, hammers, compressors, and similar machinery. The nine-spring isolator is used in mountings for 600-1,000 hp. diesel engines.



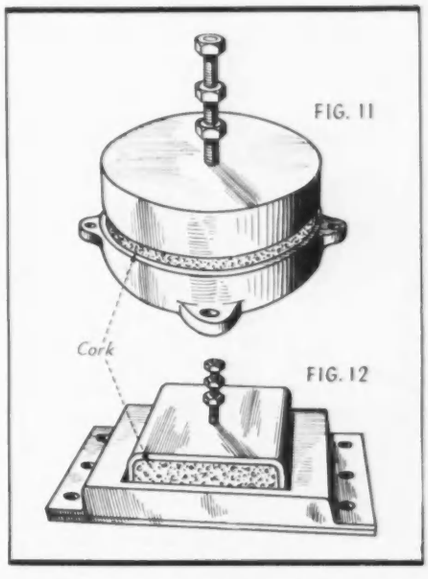
Where inertia of the foundation absorbs the forces of slow speed machinery the cylindrical damper can be used for loads of 1,500 to 3,000 lb. Heavier loads require multiple-spring installation with capacities of 5,000-25,000 lb. Type shown has a concrete sub-base, poured around channels supported on multiple-spring dampers.



This circular damper has capacities from 50 to 350 lb. Cylindrical cork filler about 4 in. in diameter is used as the isolating medium. It is suitable for overhead mounting of medium to light weight machinery as shown.



Cork in compression may be used under sub-base or machine legs. Type shown is suited to light and medium weight machines having a loading range of approximately 100 to 650 lb. for areas of 18 to 36 sq. in.

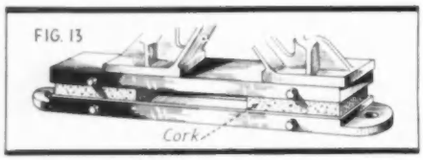


Circular cork isolator has capacity up to 550 lb. in the 6 in. diameter. The rectangular type is designed for heavier

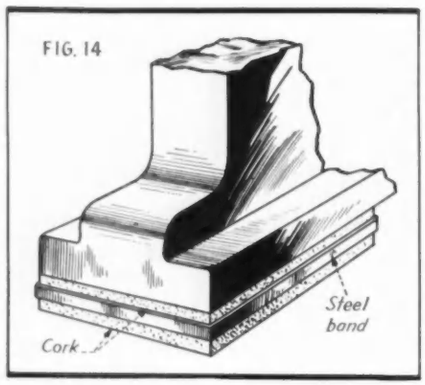
CONTINUED ON NEXT PAGE

VIBRATION ISOLATION

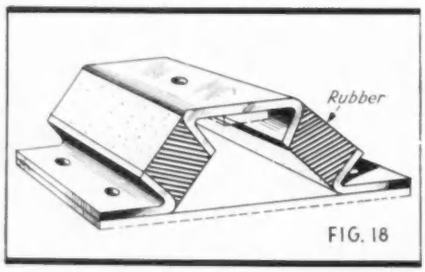
duty service, having a load range of 500 to 1,000 lb. with about 35 sq. in. of cork area.



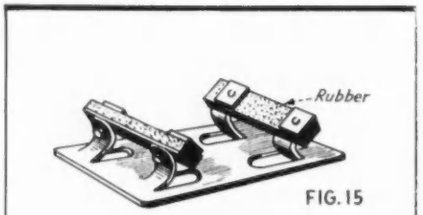
Structural shapes separated by cork isolation units allow the mounting of motor and machine on the same base. Compressors, small punch presses and machines having a drive extending beyond the machine base (causing a tendency to rock when resiliently mounted) can be mounted on this type without the use of additional bases of timber or steel.

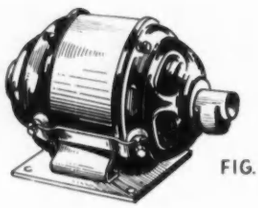


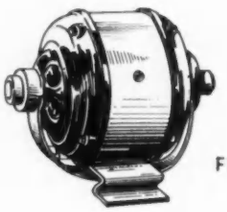
Cork slab mounted under machine base. May be used in continual contact with oil without losing efficiency. These plates are used in 3-in. thicknesses for loading of 500-3,000 lb. and natural frequencies above 650 cycles per min.; 4-in. thicknesses are used for machines operating with severe vertical impact.



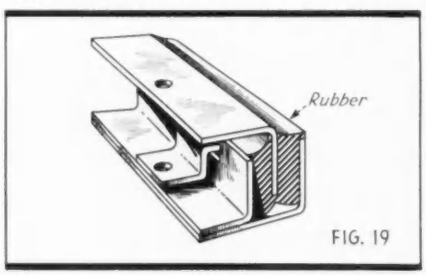
Rubber or synthetic compounds are used as the springing or isolation medium in this and the following mountings. Length can be made to suit load. With rubber of 30 durometer hardness, capacity is 40 lb. per in. of length. With hardness of 60 durometer, capacity is 105 lb. per in. of length. Natural frequency is about 310 cycles per min. Unsuitable for forced frequencies below 700.



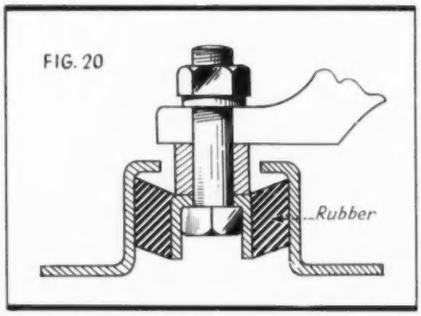




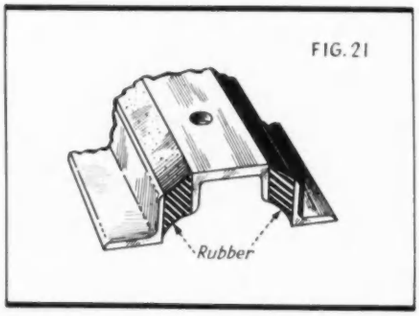
Flat springs for small motor mountings may include rubber for noise insulation. Unit shown in Fig. 15 combines springing action plus the isolation possibilities of flat rubber in compression. A similar device, Fig. 16, has rubber supported on flat springs. A garter-type spring is shown in Fig. 17.



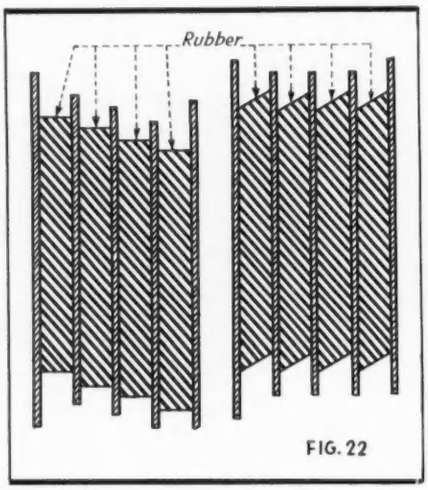
Heavy-machinery mounting, made in one length and proportioned to carry 750 to 800 lb. load with a maximum deflection of about 0.27 in., suitable for printing presses, grinders, and power hammers. Where rubber failure would cause damage, the lock bar holds the machine base approximately in position; noise generated by metal to metal contact will signal for needed replacement of rubber material.



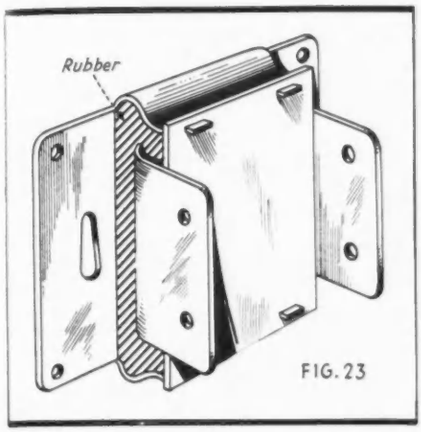
Double-shear mounting designed primarily for cushioning of vertical vibration is available in any desired length and will carry loads of 35 lb. per running in. and up depending on durometer hardness. Rubber failure will not cause damage as machine base will come to rest on channel. Used for motion-picture apparatus, and sensitive precision tools.



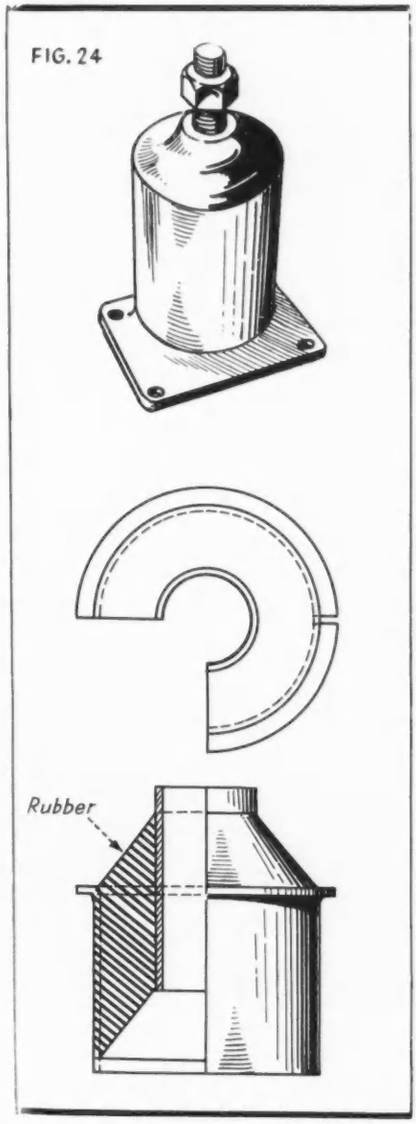
Similar double shear mounting designed to suport about 50 lb. per running in. at a frequency of 800 to 1,000 cycles per min. When used at a frequency of 400 to 500 cycles per min. loading should be 60 to 50 per cent of recommended maximum.



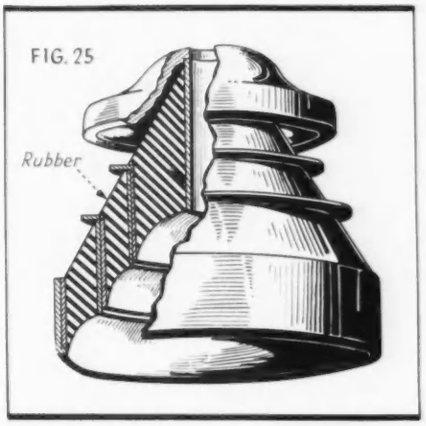
When large deflections in the shear plane are required to get the necessary amount of reduction in transmissability combined with smaller deflections at right angles rubber sandwiches can be used.



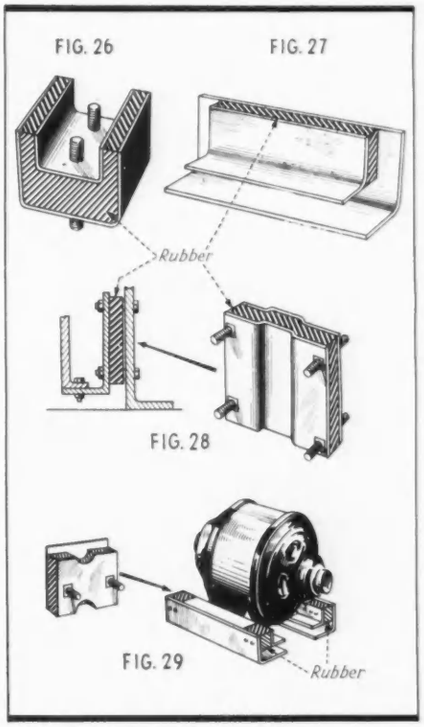
Rubber spring is designed for general industrial service where variable torque is encountered. Design employs the double shear principle plus compression, and is available in ratings of 500 to 800 lb.



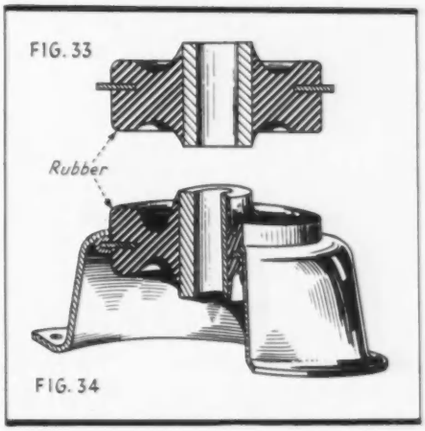
Lateral stability is provided in all planes by this rubber spring. The rubber is fastened to a central steel tube and to an outer split-steel shell made in two halves. F. L. Haushalter gives the formula for calculating sizes of mounting in his paper "Rubber as a Load Carrying Material." *S. A. E. Journal*, January, 1939.



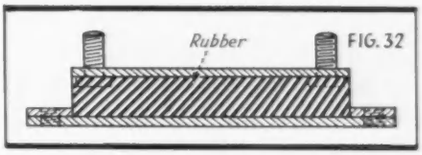
Multiple rubber spring used when large deflections are desired. Rubber of different hardness can be used in the different stages to get any desired deflection curve. The umbrella type top cuts out the various stages to prevent overloading and gives control of the deflection characteristics of the spring. Mountings similar to this are used in subway and street-car truck mountings.



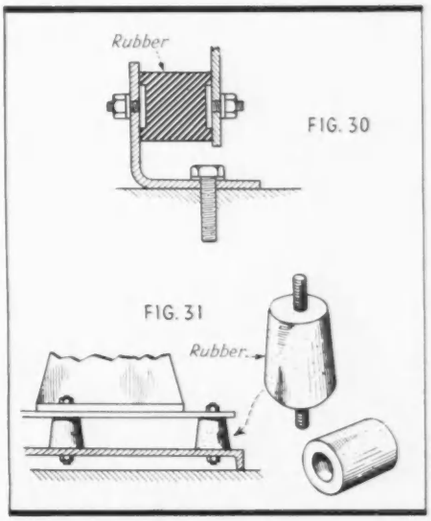
Single-shear mountings for various aplications and in various capacities include mountings used on the Plymouth automobile. Fig. 26, while the others are standard types of single shear sandwich mountings.



Circular and mechanical-type mountings for lightly-loaded machinery. Fig. 30, use rubber in single shear or in combination shear and compression.



Used in single shear or compression, or both, this vibration mounting uses a rubber of 30 durometer hardness, has a capacity in shear of about 200 lb., and in compression of 600 lb., with 6½ sq. in. area.



Small shear-type mountings with a flat plate outer member are used for instrument and panel board installations, and similar lightly loaded items. Cylindrical springs, used for heavier equipment, isolate engine vibration from the supporting structure in aircraft and automotive work. Mountings for mobile installations frequently incorporate a snubbing feature to limit movement under shock or overload.

COMPRESSION SPRING ADJUSTING

In this concluding group of adjustable compression springs, several methods are shown in which some form of anti-friction device is used to make adjustment easier. Thrust is taken against either single or multiple steel balls, the latter including commercial ball thrust bearings. Adjustments of double spring arrangements and other unconventional methods are also illustrated

HENRY MARTIN

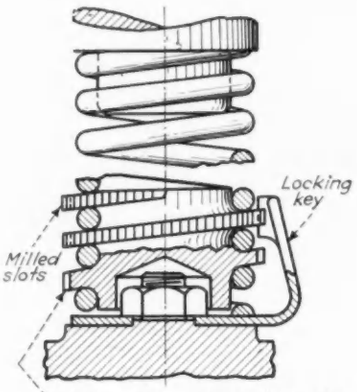


FIG.18

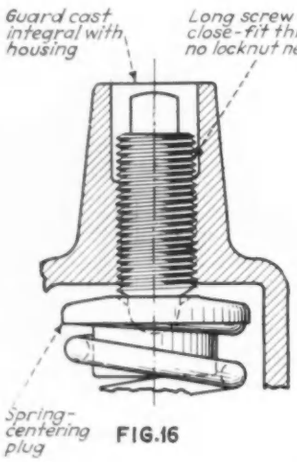


FIG.16

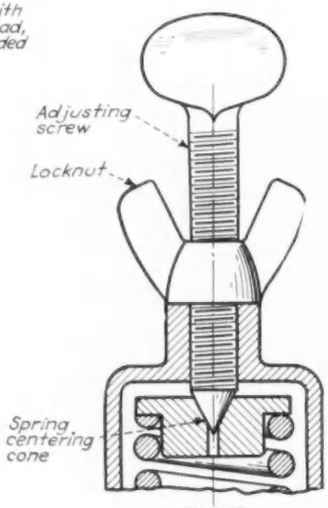


FIG.17

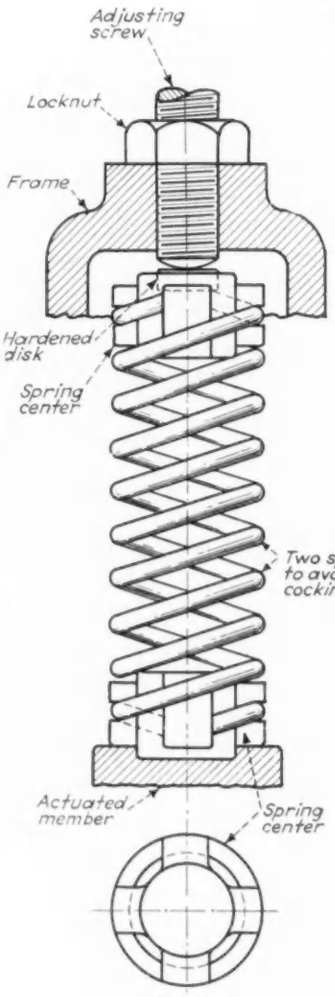


FIG.21

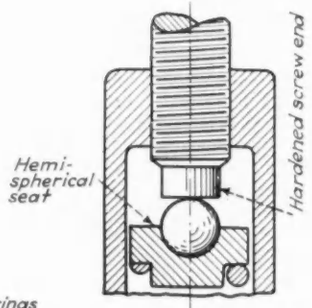


FIG.22

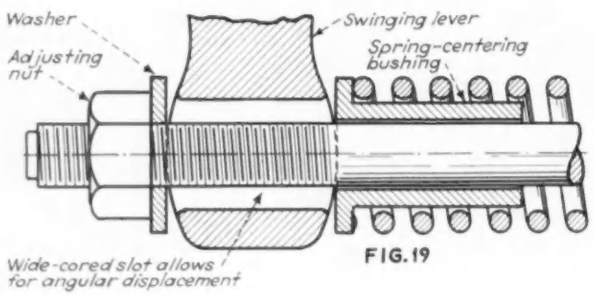


FIG.19

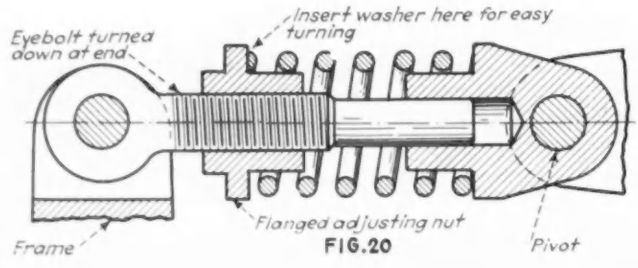


FIG.20

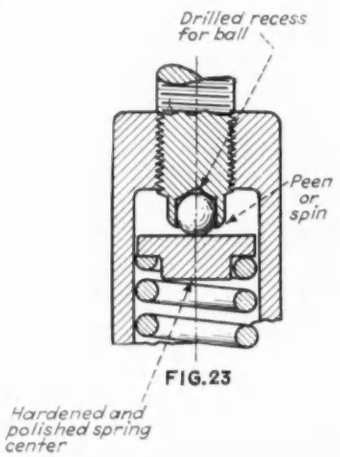


FIG.23

METHODS—II

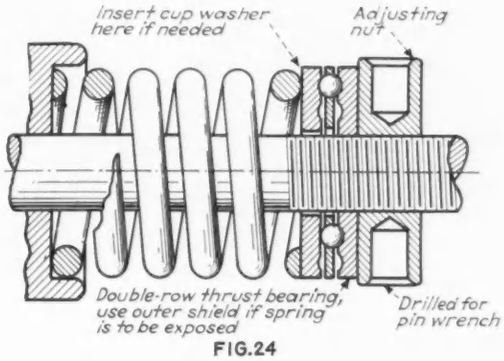

Insert cup washer here if needed
Adjusting nut
Double-row thrust bearing; use outer shield if spring is to be exposed
Drilled for pin wrench

FIG. 24

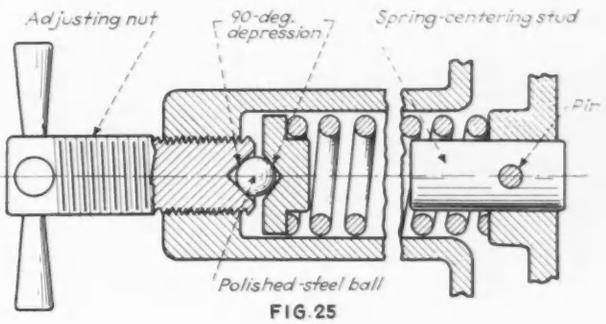


FIG. 25

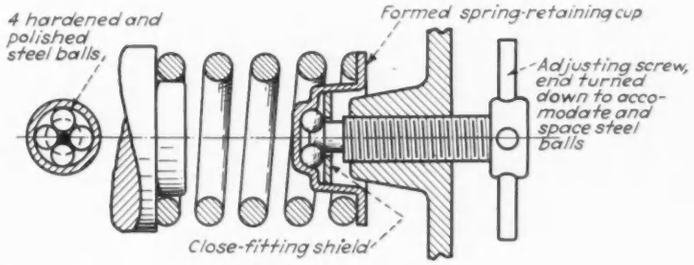

4 hardened and polished steel balls
Formed spring-retaining cup
Adjusting screw, end turned down to accommodate and space steel balls
Close-fitting shield

FIG. 26

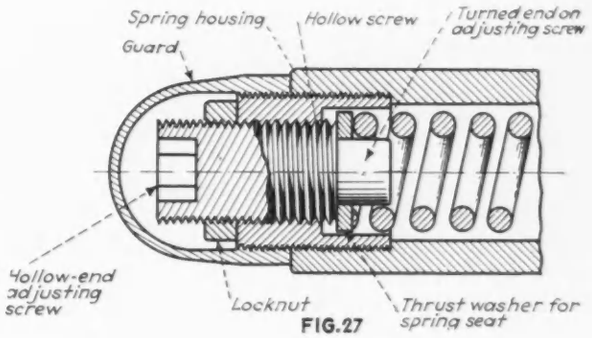


FIG. 27

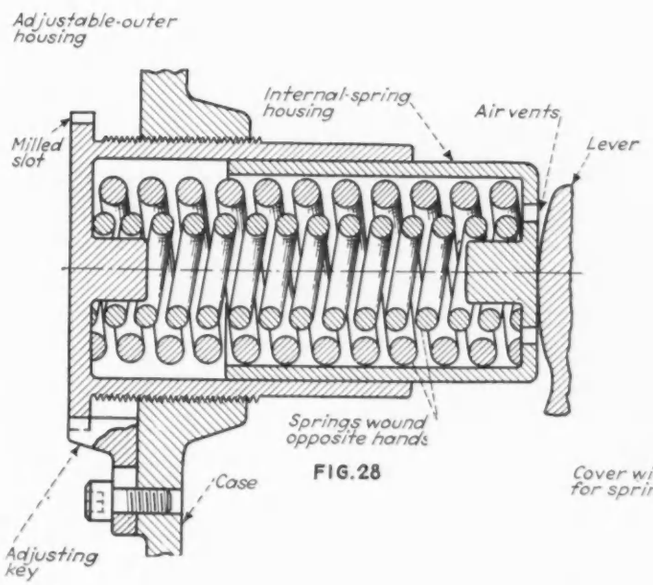


FIG. 28

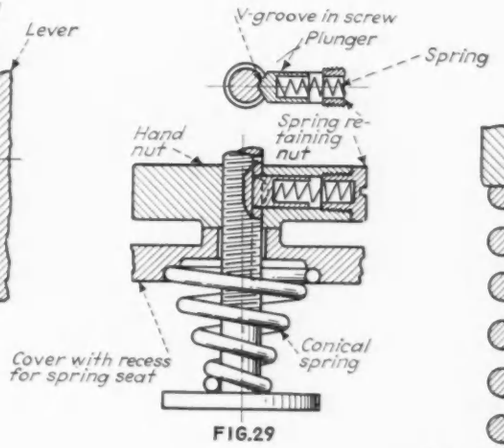


FIG. 29

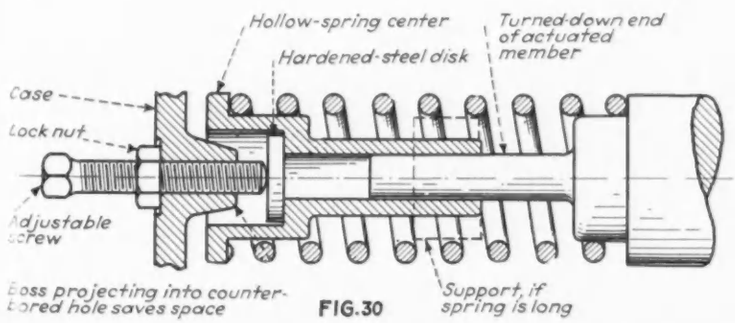


FIG. 30

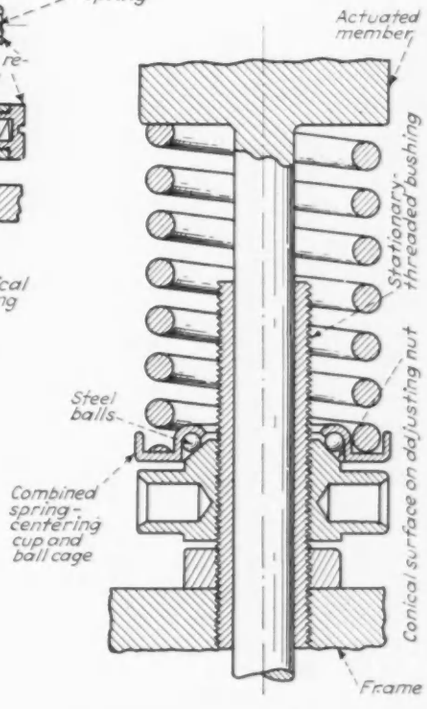


FIG. 31

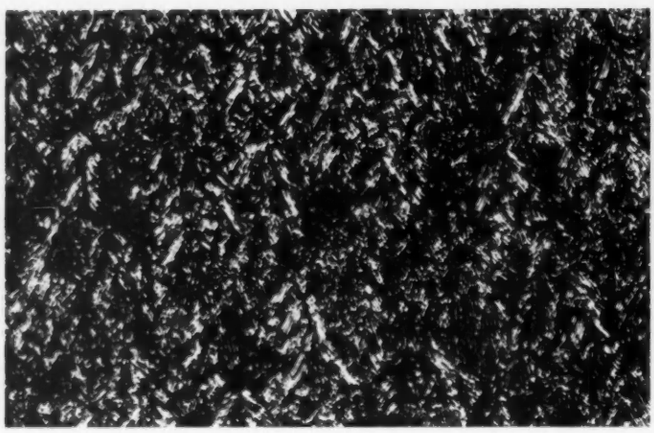
TWELVE EFFECTS WITH WRINKLE

THE VERSATILITY of wrinkle finish and some of the effects which can be obtained are indicated by the accompanying illustrations. These show some of the types of finishes which have been applied to automobile radios, business machines, air conditioning equipment, and other metal or heat-resistant material covered units.

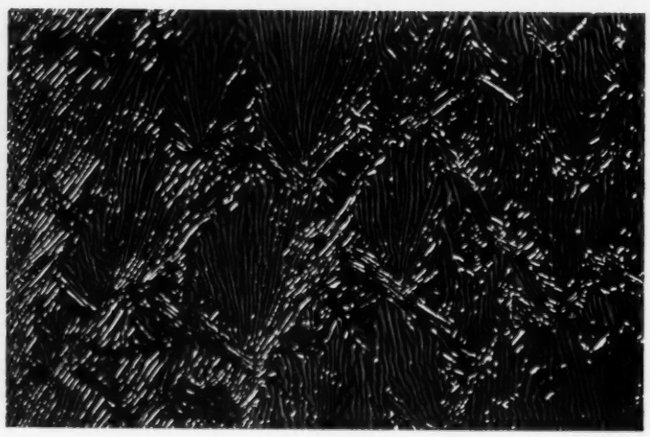
There are two main factors that must be carefully controlled to get uniform results when applying these finishes. These are: uniform heat in the baking oven; a clean spray gun nozzle so that the spray will come out in a uniform pattern. Dust in the finishing room ordinarily does not mar the finish. Flaws in wrinkle-finished surfaces are not apparent to the naked eye so the finisher need exercise only ordinary care in avoiding "sags" or "runs."

When pastel colors instead of standard colors are being considered caution must be exercised in the selection regardless of the effect desired. Pastel shades are susceptible to overheating and care must be exercised to retain the color effect originally desired. Because they are delicate, too much heat has a tendency to burn the colors. This is not true of standard colors because their pigments are basic and not a combination such as is required for pastel shades.

PINE TREE AND SAG WRINKLE FINISHES

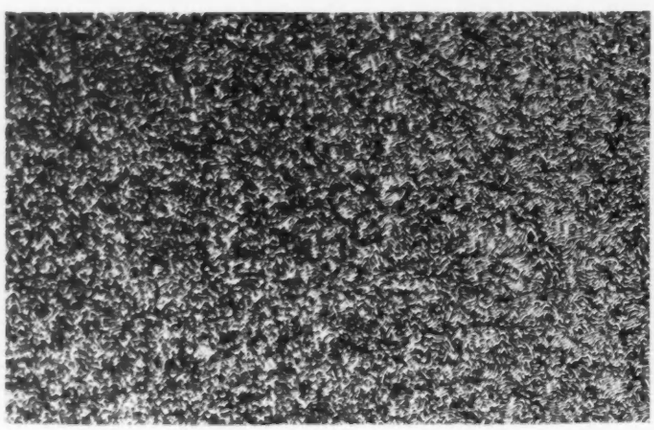


Pine tree wrinkle, as its name implies, looks like miniature pine trees uniformly distributed over the entire finished area. The appearance is caused by small "runs" which set immediately when subjected to heat. A bake of 225 deg. F. is required. Heavy, medium or small design is governed by the adjustment of the spray gun nozzle which will regulate the amount of material being sprayed.

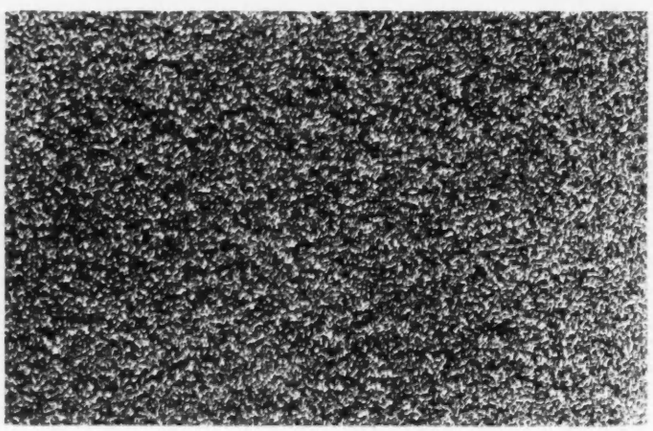


Sag wrinkle is used in either a heavy or medium grade. A combination phenolic resin, varnish and synthetic base is applied to metals or other materials which will stand heat. It must be sprayed heavy enough to create "runs" giving the appearance of draped curtains. It is then baked at 225 deg. F. for three hours. Grade shown here is medium. Spray nozzle setting determines grade of finish.

OPALESCENT WRINKLE FINISHES



Opalescent wrinkle is basically the same as the uniform wrinkle shown on the next page. The difference in finish is acquired by adding opalescent materials to the uniform finish formulas to give them a more variant color effect, such as an

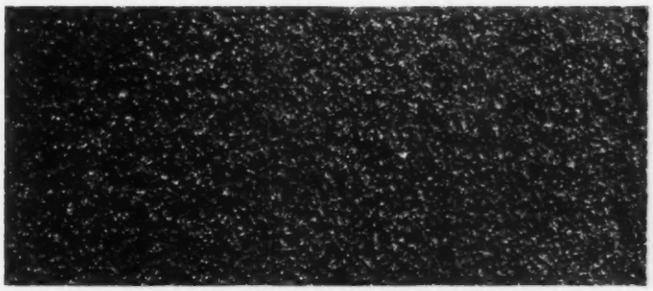


irridescent array of pearl-like colors, as contrast to solid colors. The finishes shown here are medium and fine grades. A coarse and a very fine grade are also available. Decorative possibilities make these finishes suitable for household equipment.

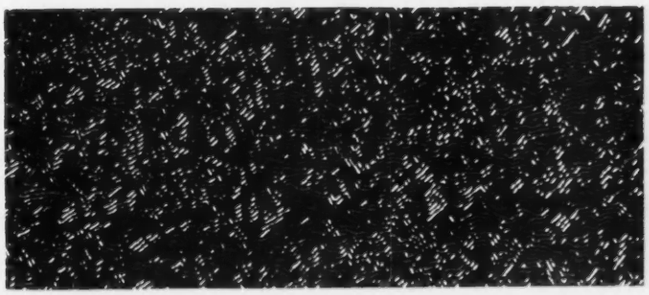
FINISH

UNIFORM WRINKLE FINISHES

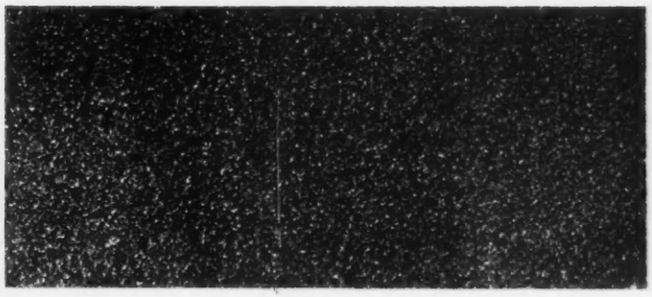
EXTRA HEAVY



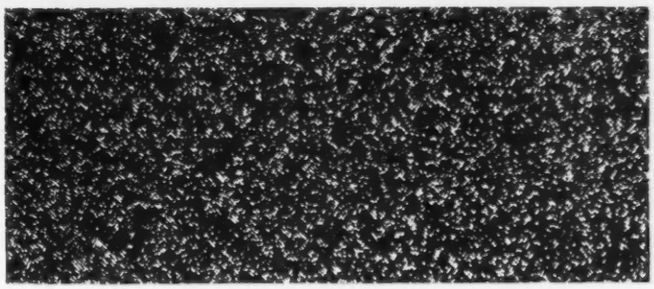
SMALL



HEAVY



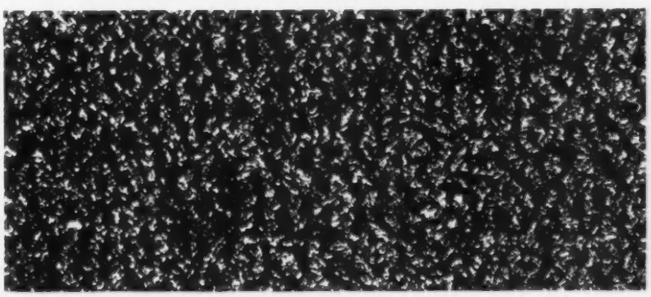
VERY SMALL



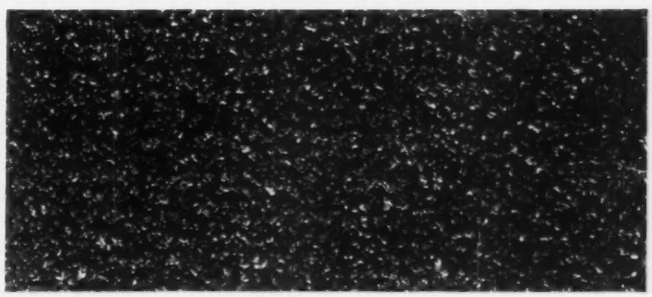
MEDIUM

Uniform wrinkle finish establishes uniform design over the entire finished surface with each individual wrinkle identical in size and character. It can be used in the five weights shown here: extra heavy, heavy, medium, small and very small. Unlike sag or pine tree wrinkle where one formula is used for all the weight finishes, each classification for uniform wrinkle finish requires a different formulation. Each is applied in the same manner with the same nozzle setting on the spray gun. Where synthetic formulas are used it is only necessary to bake this type at 225 deg. F. for one hour.

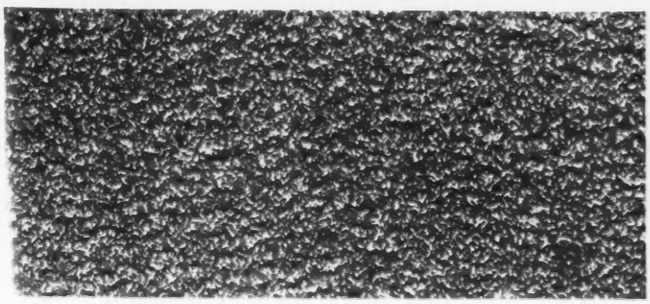
"BIRD'S EYE" WRINKLE FINISHES



HEAVY



SMALL



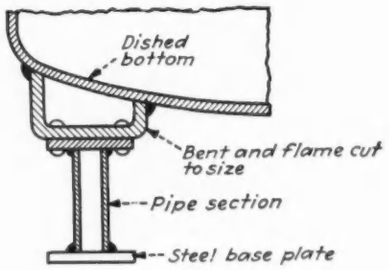
MEDIUM

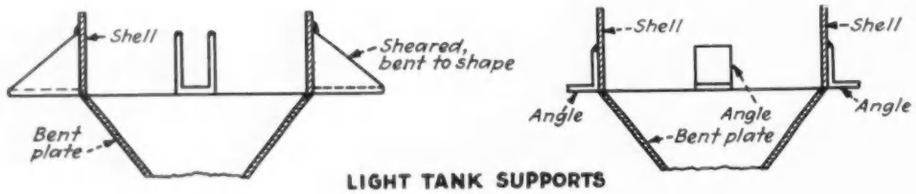
"Birdseye" or "fisheye" wrinkle is used on better grade products such as laboratory equipment and appliances. While it requires more care in application than any of the other types, complications can be overcome by practice and good judgment on the part of the finisher. Only one formulation is required for the three grades. Difference in apearance is accomplished by varying the amount of material sprayed. After spraying the product is baked for one-half hour at a temperature of 100 to 150 deg. F. This sets the "eyes" after which the parts are finish baked at 225 deg. F. for three hours.

BUILT-UP WELDED CONSTRUCTIONS

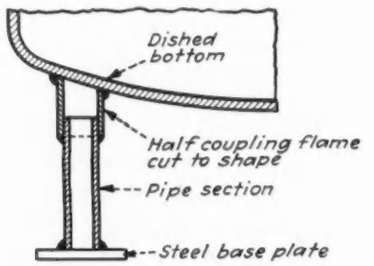
Details illustrated, taken from designs for sanitary and chemical processing equipment, represent utilization of diversified metal-working equipment—bending rolls, power presses, flangers and such—to fabricate functionally correct parts from simple sheet and fittings. Commercial shapes are used where practical; but parts are flame-cut, forged or rolled when such fabrication is more economical or design requirements dictate

O. W. FISHER
Chief Engineer, L. O. Koven & Brother, Incorporated

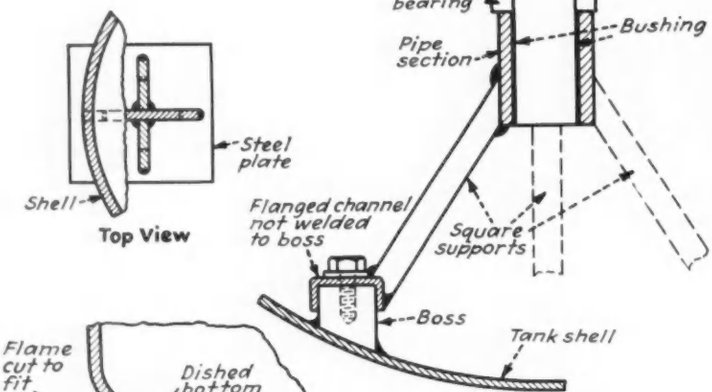




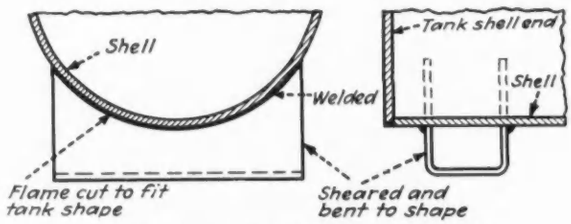
LIGHT TANK SUPPORTS



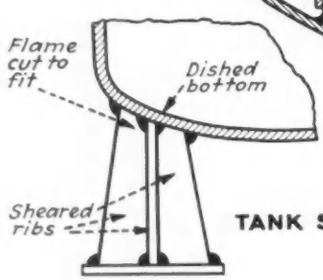
BUILT-UP SUPPORTS



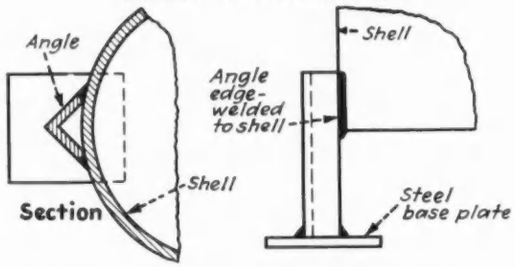
SHAFT SUPPORT

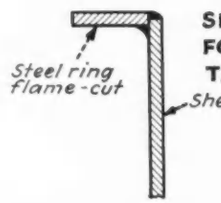


SUPPORT FOR LIGHT LOADED LARGE DIAMETER TANK

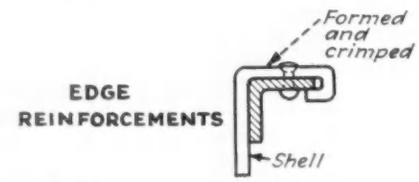


TANK SUPPORT

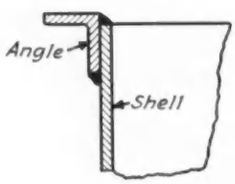


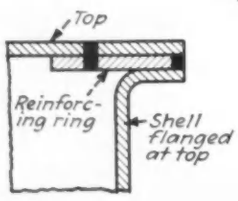


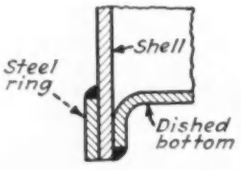
SIMPLE SUPPORT SUITABLE FOR CIRCULAR OR SQUARE TANKS

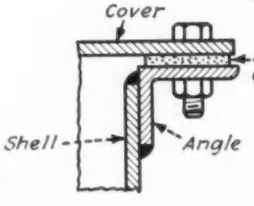


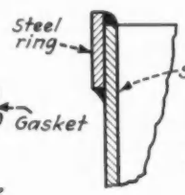
EDGE REINFORCEMENTS

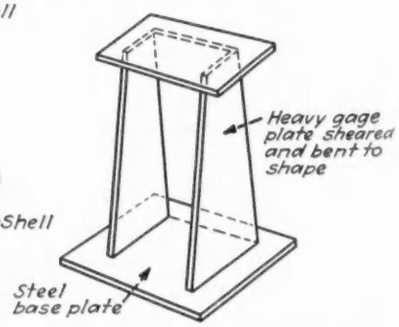




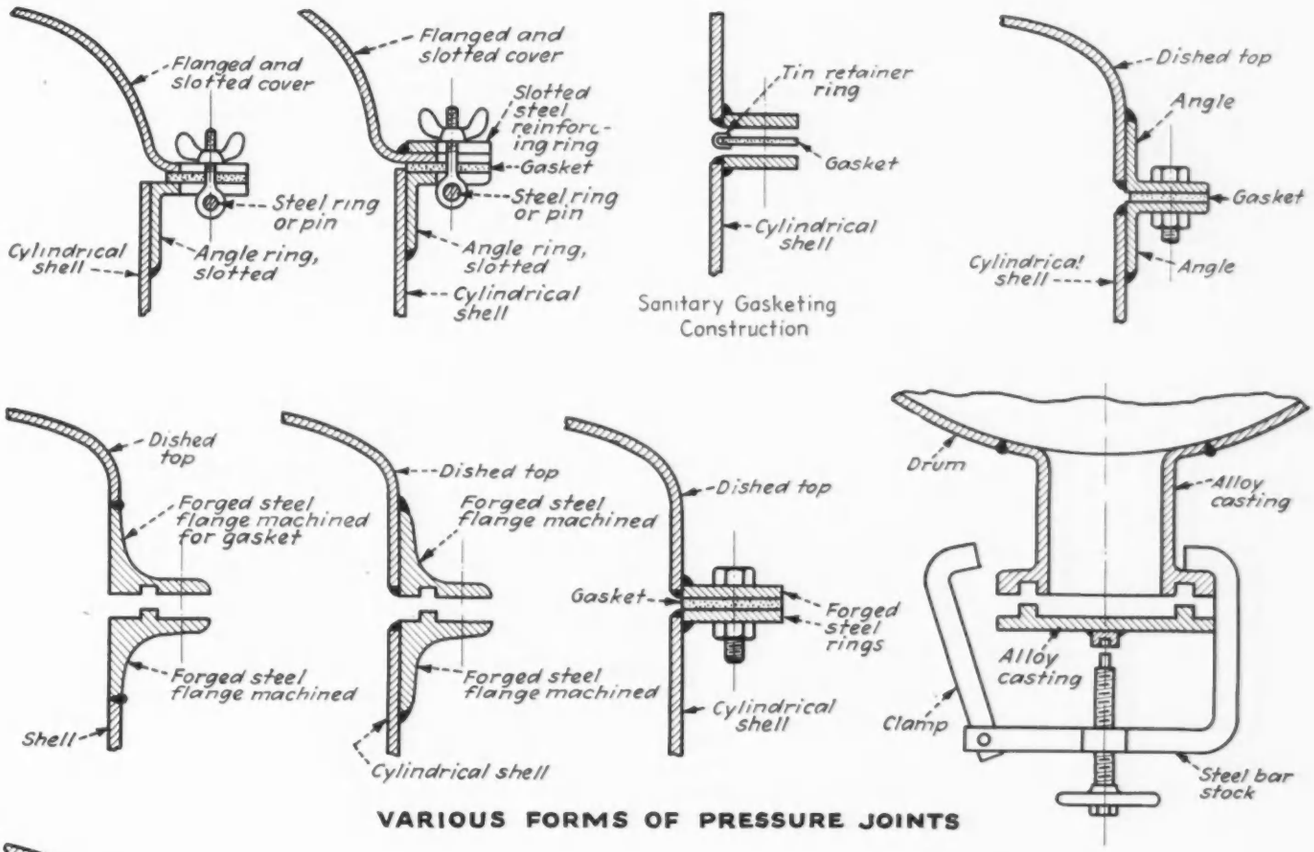




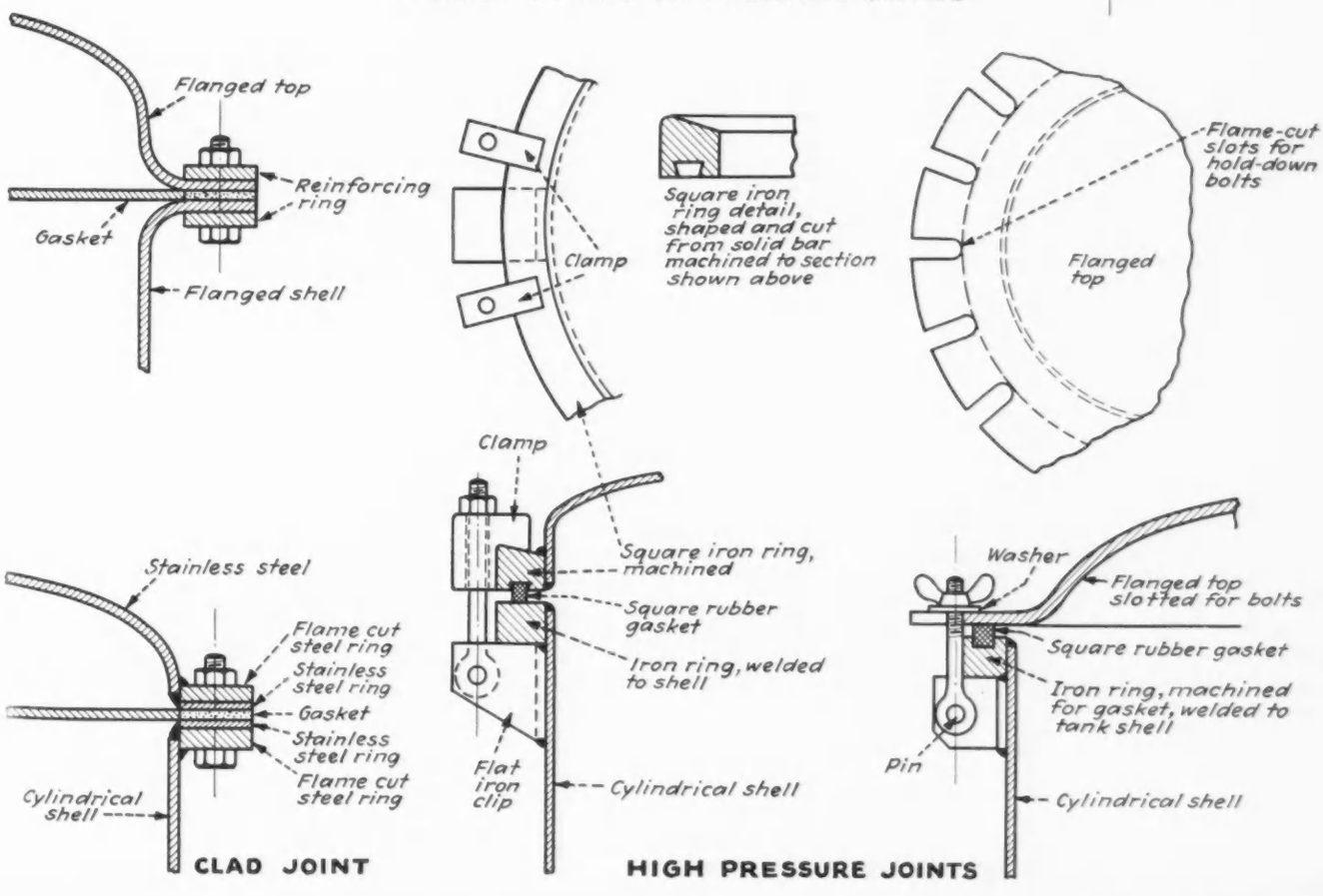




SIMPLE TANK SUPPORT



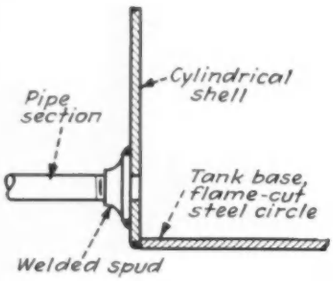
VARIOUS FORMS OF PRESSURE JOINTS

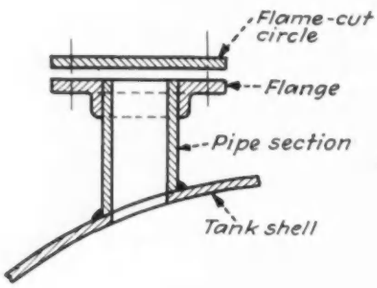


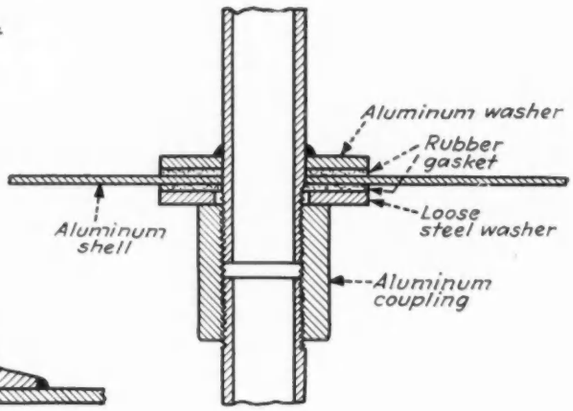
CLAD JOINT **HIGH PRESSURE JOINTS**

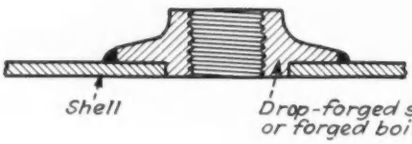
CONTINUED ON NEXT PAGE

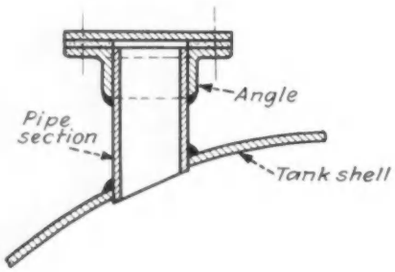
BUILT-UP WELDED CONSTRUCTIONS

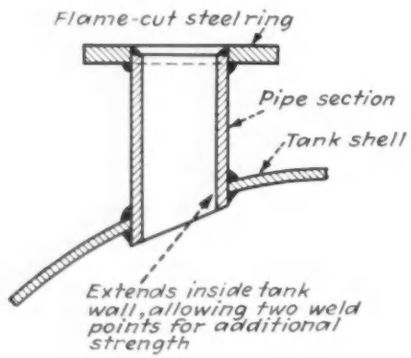


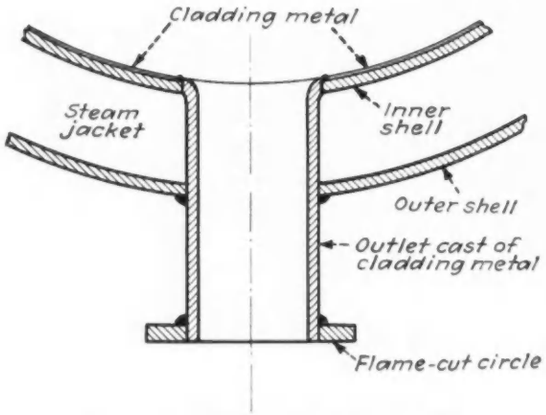


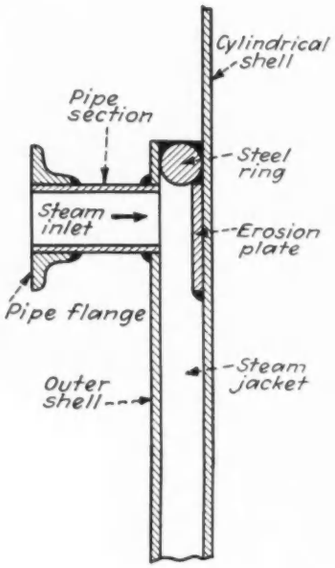




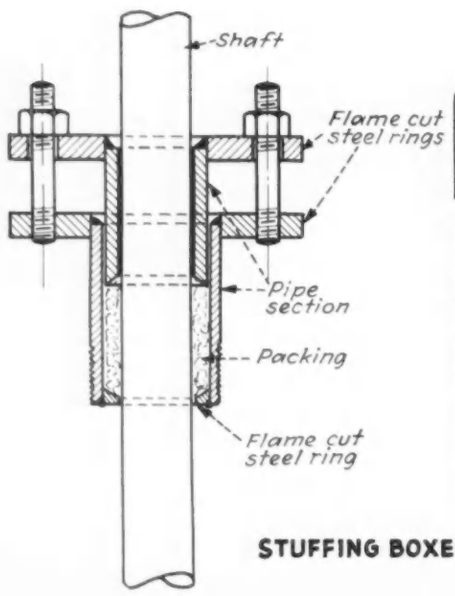


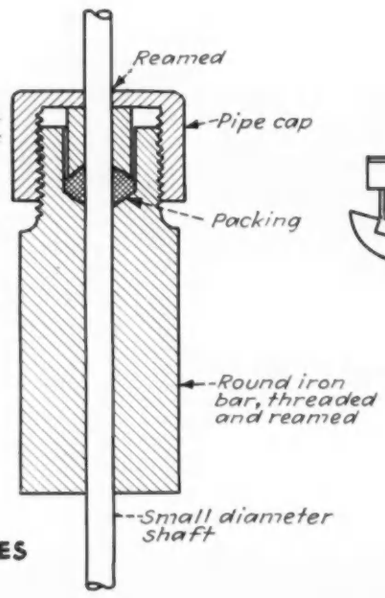

Flame-cut steel ring
Pipe section
Tank shell
Extends inside tank wall, allowing two weld points for additional strength





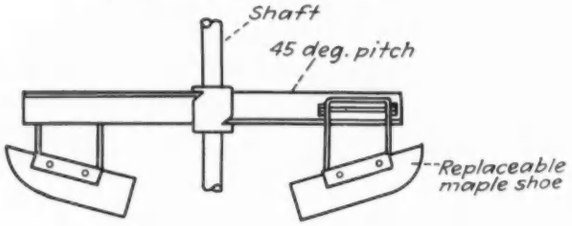
BUILT-UP INLETS AND OUTLETS

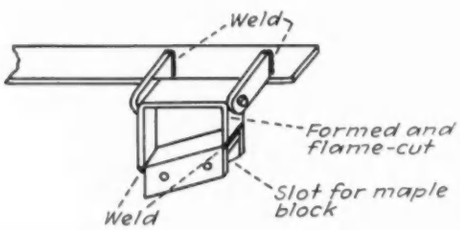


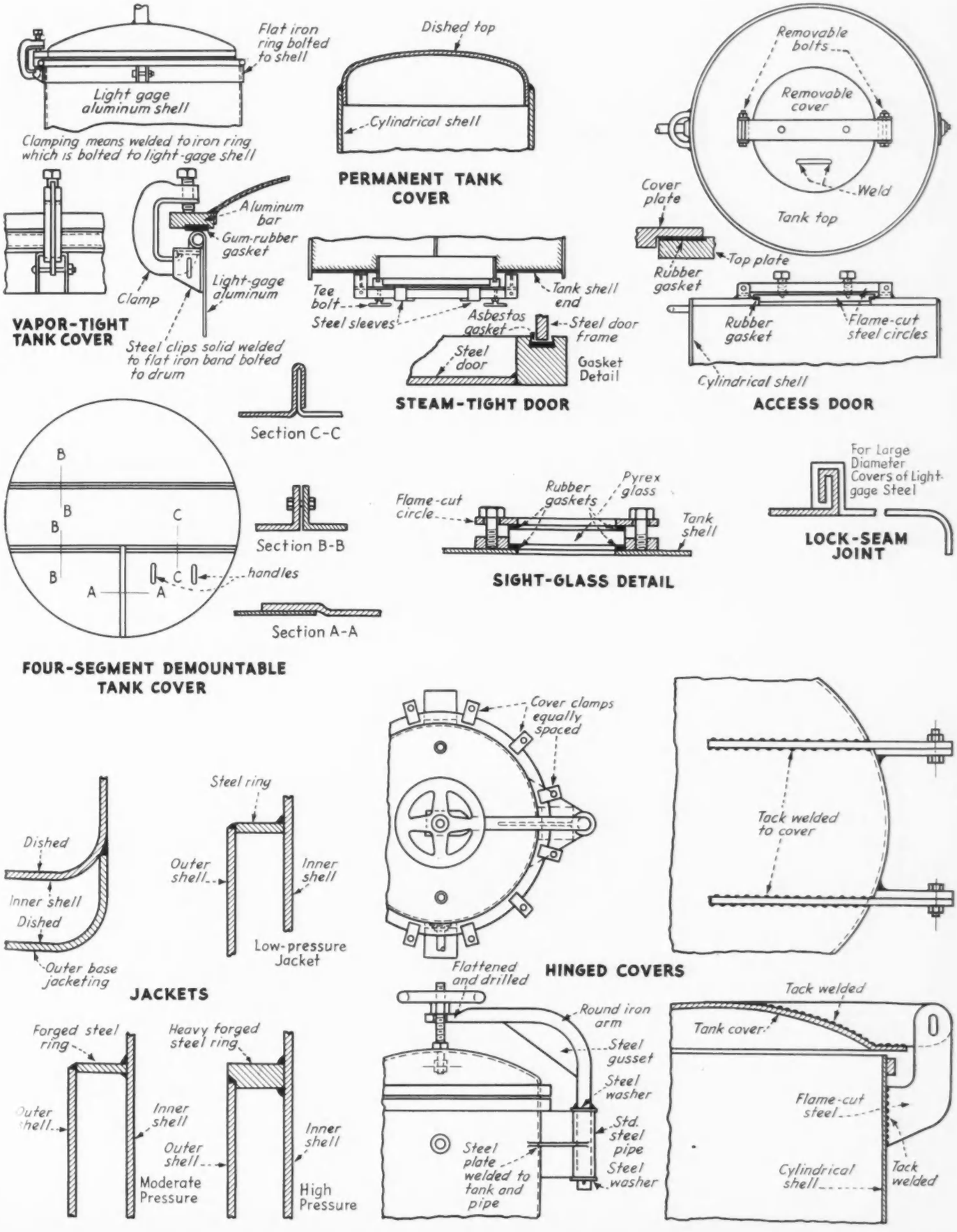


STUFFING BOXES

BUILT-UP AGITATOR— SANITARY PROCESSING






Flat iron ring bolted to shell
Light gage aluminum shell
Clamping means welded to iron ring which is bolted to light-gage shell
Dished top
Cylindrical shell
PERMANENT TANK COVER
Removable bolts
Removable cover
Weld
Tank top
Cover plate
Top plate
Rubber gasket
Rubber gasket
Flame-cut steel circles
Cylindrical shell
ACCESS DOOR
Aluminum bar
Gum-rubber gasket
Light-gage aluminum
Clamp
Steel clips solid welded to flat iron band bolted to drum
VAPOR-TIGHT TANK COVER
Tee bolt
Steel sleeves
Asbestos gasket
Steel door frame
Steel door
Gasket Detail
Tank shell end
STEAM-TIGHT DOOR
Section C-C
Section B-B
Section A-A
handles
FOUR-SEGMENT DEMOUNTABLE TANK COVER
Flame-cut circle
Rubber gaskets
Pyrex glass
Tank shell
SIGHT-GLASS DETAIL
For Large Diameter Covers of Light-gage Steel
LOCK-SEAM JOINT
Dished
Inner shell
Dished
Outer base jacketing
Steel ring
Outer shell
Inner shell
Low-pressure Jacket
JACKETS
Cover clamps equally spaced
Tack welded to cover
HINGED COVERS
Forged steel ring
Heavy forged steel ring
Outer shell
Inner shell
Outer shell
Inner shell
Moderate Pressure
High Pressure
Flattened and drilled
Round iron arm
Steel gusset
Steel washer
Std. steel pipe
Steel washer
Steel plate welded to tank and pipe
Tack welded
Tank cover
Flame-cut steel
Cylindrical shell
Tack welded

FLEXIBLE SHAFTS AND CASINGS

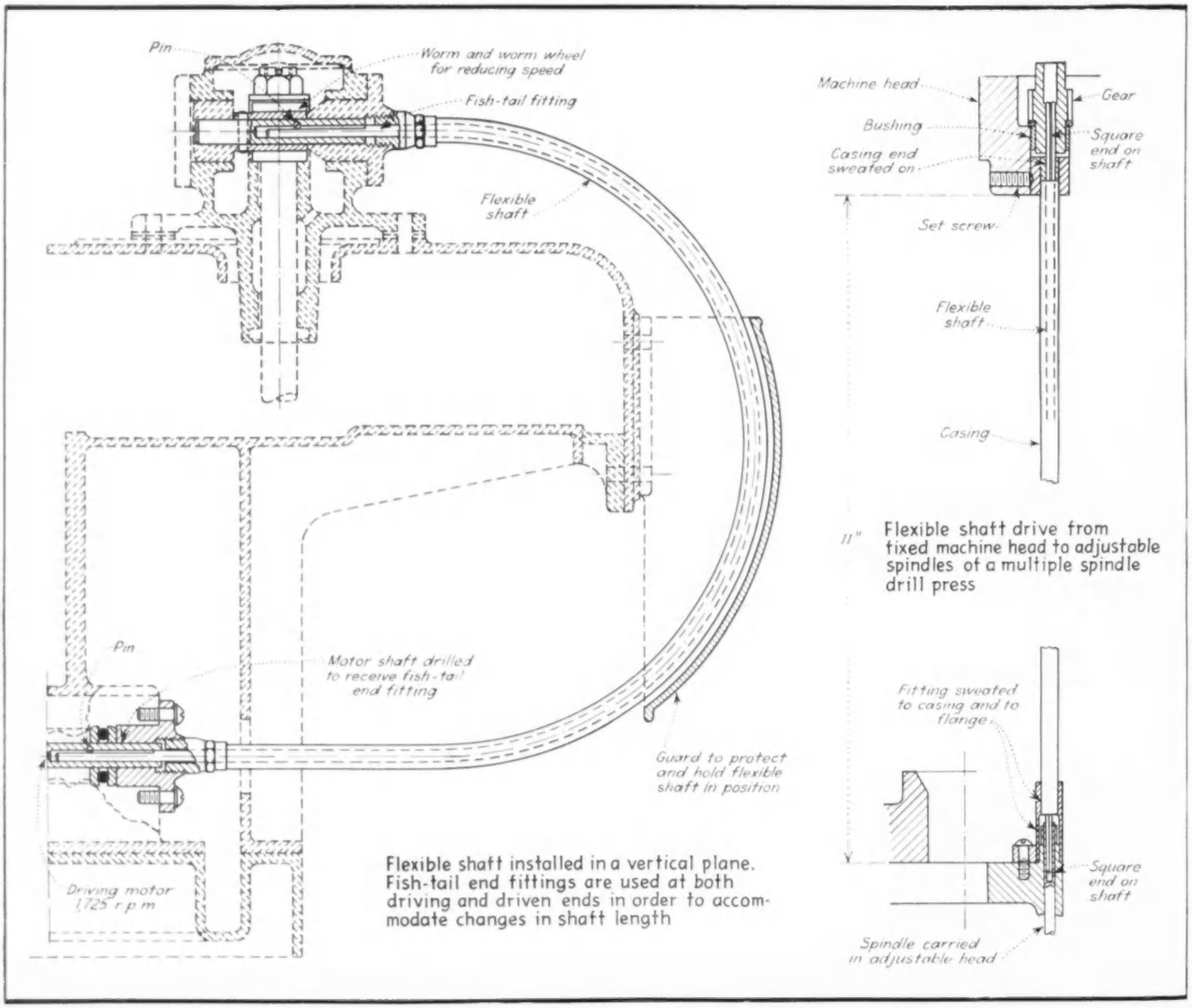
FOUR IMPORTANT FACTORS are generally considered by designers when selecting a flexible shaft to transmit power from a driving to a driven unit. These factors are: the torque to be transmitted, the minimum radius of curvature to which the shaft is expected to conform, the amount of torsional twist or lag that is permissible in the total length of shaft, and the length of shaft required.

The torsional strength of flexible shafting usually is not of the same value for both directions of rotation, this characteristic is inherent in the method of construction. Flexible shafts are made up of layers or wrappings of wire over a central wire mandrel or core, with the direction of winding or coiling alternating with each layer. The manufacturer of the shafting selects the sizes and materials of the winding wires so that the torsional strength of the composite shaft will be as nearly equal as is possible for both directions of rotation.

Power drive flexible shafting is available in sizes and constructions having ultimate torsional strengths ranging from 1½ to 575 lb. in. torque in a direction of rotation the same as that of the winding of the outside layer. Recommended running or working torques range from 0.38 lb. in. to 143.8 lb. in. for straight shafts. These values are considerably reduced when the shaft is curved, since curving increases the friction of the wires as they flex while rotating. However, the ratio of reduction is not the same for all shafts but is dependent upon the material used and the winding design.

When rotating under load, the wires of the flexible shaft tighten and stretch so that there is an initial lag in angular displacement between the driving and the driven ends. For specific shafts this lag is proportional to the amount of torque transmitted and also the length of the shaft. The torsional deflection per lb. in. of torque per ft. of length of shaft varies from over 200 deg. in the smaller sizes to as little as 0.1 deg. in the larger sizes.

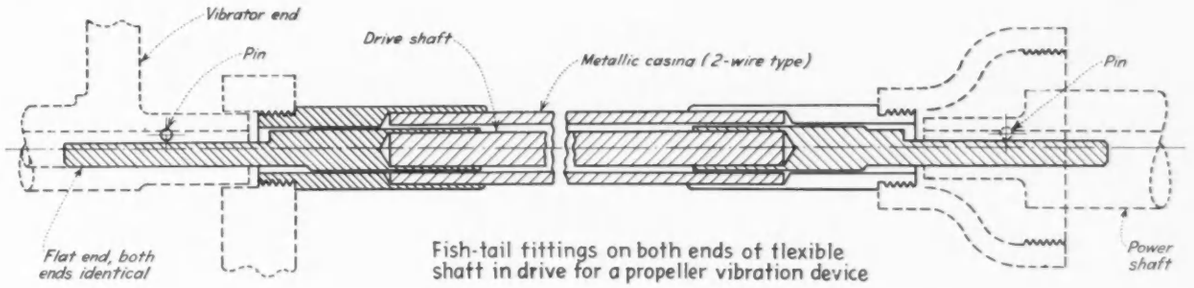
Flexible shafts can be furnished in practically any required length. The longer the shaft the greater is its own frictional load and the greater is the total torsional deflection from end to end. With long shafts there is also a tendency when under fluctuating loads to deliver an irregular driving moment at the driven end. In applications where synchronism of the driving unit with the driven unit is important the torsional deflection in the shaft should be considered.



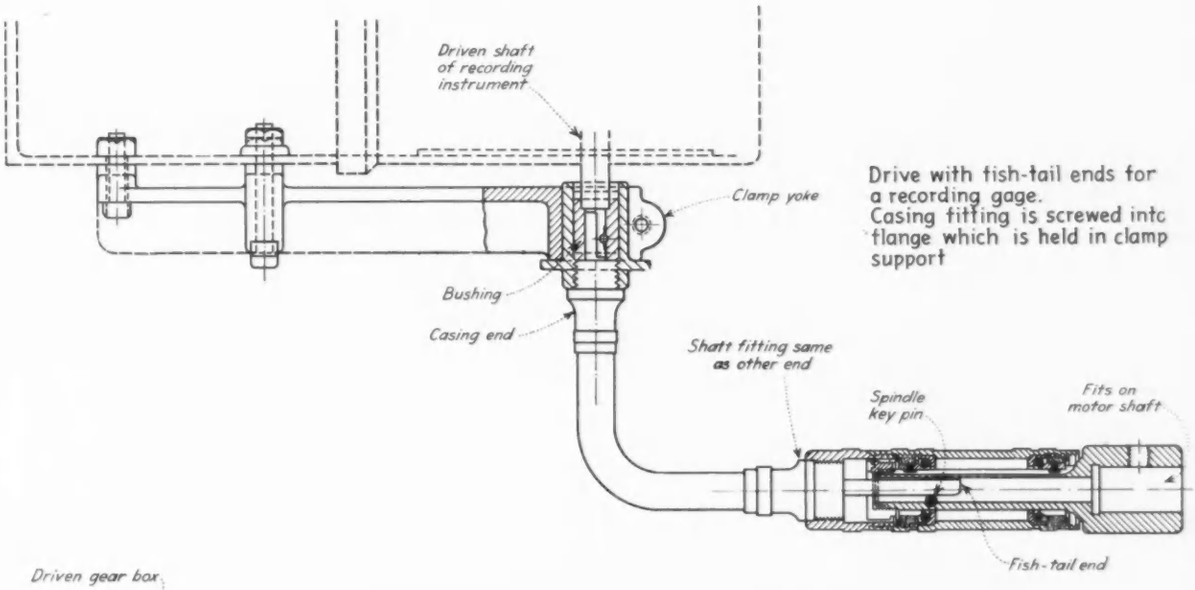
Flexible shaft installed in a vertical plane. Fish-tail end fittings are used at both driving and driven ends in order to accommodate changes in shaft length

11" Flexible shaft drive from fixed machine head to adjustable spindles of a multiple spindle drill press

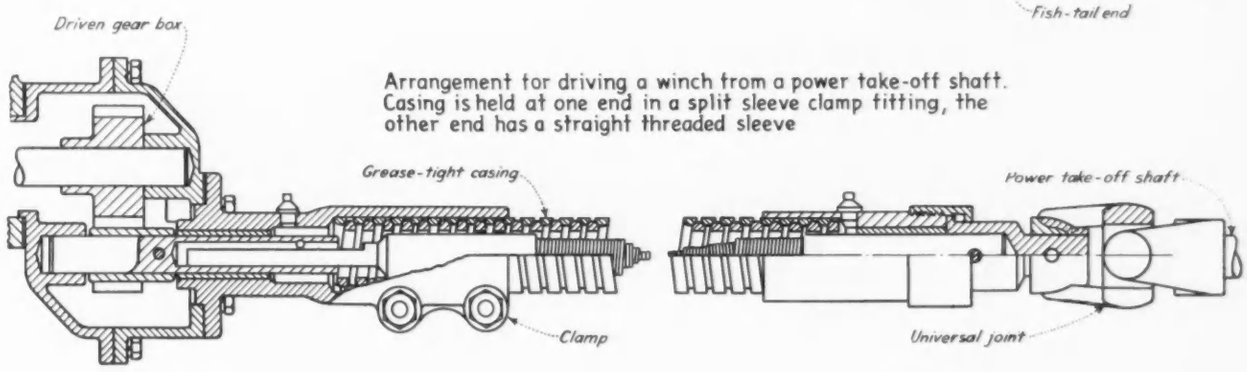
ILLUSTRATIONS COURTESY OF S. S. WHITE DENTAL MANUFACTURING COMPANY



Fish-tail fittings on both ends of flexible shaft in drive for a propeller vibration device



Drive with fish-tail ends for a recording gage. Casing fitting is screwed into flange which is held in clamp support



Arrangement for driving a winch from a power take-off shaft. Casing is held at one end in a split sleeve clamp fitting, the other end has a straight threaded sleeve

For special purposes shafts as long as 50 ft. have been used satisfactorily. For straight driving, where there are no special requirements, lengths up to 25 ft. are generally used.

Operating speeds of 1,750 to 3,600 r.p.m. are recommended for flexible power shafts although there are no definite limitations on speed from the standpoint of design. If conditions are such that there is a choice of speed, it is preferable, because of cost considerations, to run the shaft at the highest speed possible, since for a given horsepower the higher the speed the less will be the torque transmitted and the smaller will be the diameter of the shaft required.

For operating controls, either manually or automatically, a type of flexible shafting is employed that differs in construction from the type designed to transmit power. Flexible shafting for remote controls is wound of finer wire, thereby giving more layers than for the same diameter of power type shaft. Consequently the torsional deflection is less than it is in the power type shaft.

When selecting control flexible shafts for any application a choice of size

FLEXIBLE SHAFTS AND CASINGS

should be made only after consideration is given, as is done in choosing power shafting, to the torque that is to be transmitted, radius of minimum curvature, permissible torsional twist, and length of shaft required.

Control type shafts are available with ultimate strengths ranging from 14 to 275 lb. in. torque. Torsional deflection per lb. in. of torque per ft. of length of shaft varies from 10 to 6 deg. and is dependent upon size, type of construction, material used and direction of rotation.

Gear pairs with step-up ratios are sometimes introduced in the driving arrangements in order to make possible the use of a small diameter shaft at high speed rather than a large diameter shaft at slow speed, and thus obtain economy in initial cost of shaft, less angular deflection and consequent smoother operation. Step-up gears are also used where the shaft is long and it is desirable to reduce weight, as in some aircraft applications.

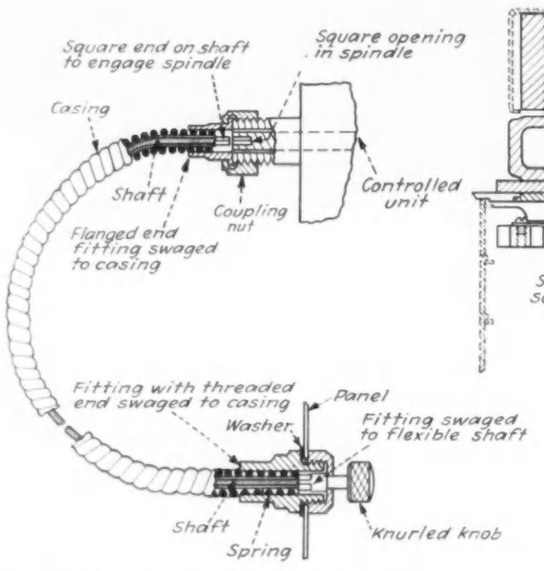
To protect flexible shafting from dust, grit and damage through contact with other bodies, to prevent the shaft from being bent too sharply and to provide bearings which hold the shaft in a desired position for smooth operation, flexible casings are required.

Casings are made flexible yet with enough stiffness to stay put in a flexed position, and also with sufficient spring tension to prevent kinking or bending too sharply. Casings also are resistant enough to elongation to maintain a constant length.

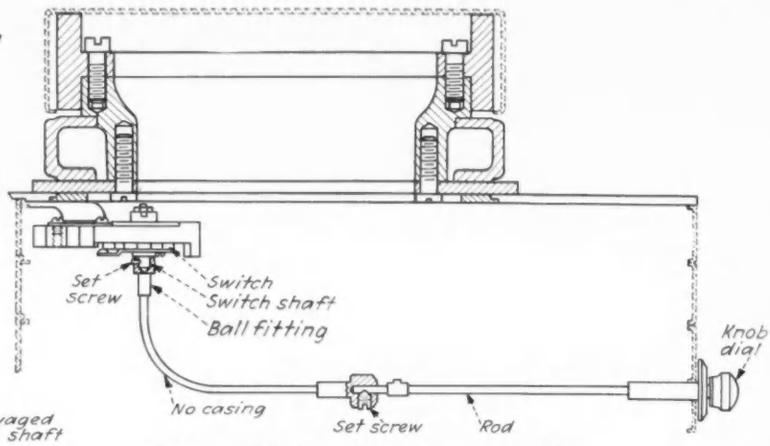
For power shafts, casings are either made entirely of metal or have a metal liner. Fabric, rubber and synthetic materials in various combinations are used in outside coverings for the metal liner as a seal against water or oil. Metal casings can be furnished plated, Parkerized, japanned or galvanized. Bronze and aluminum casings are also available.

End fittings for flexible shafting are of many forms. Except for very short lengths, flexible shafts should be installed so that one or both end fittings permit some free axial motion of the shaft in the coupling in order to accommodate the changes in shaft length because of flexing and curving. To receive the end fittings flexible shafts are furnished with ends swaged into square or octagonal cross-sections, accurately sized with smooth surfaces to fit broached holes. Some types of end fittings are brazed or sweated to the shaft. Set screws are also used for fastening the fittings to the shaft.

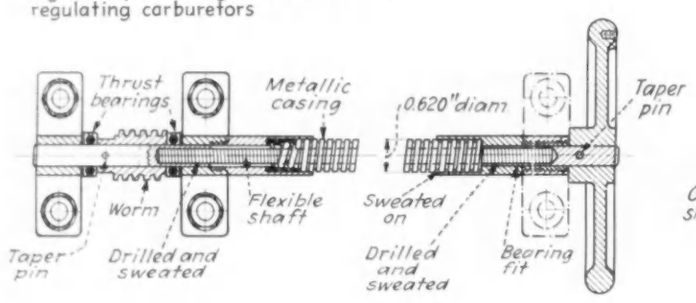
There is also a variety in the design of end fittings for connecting casings to supporting parts, some of which provide a bearing for the end fitting of the shaft. Often in portable tools the bearing is supported in a sleeve to which the casing end fitting is attached.



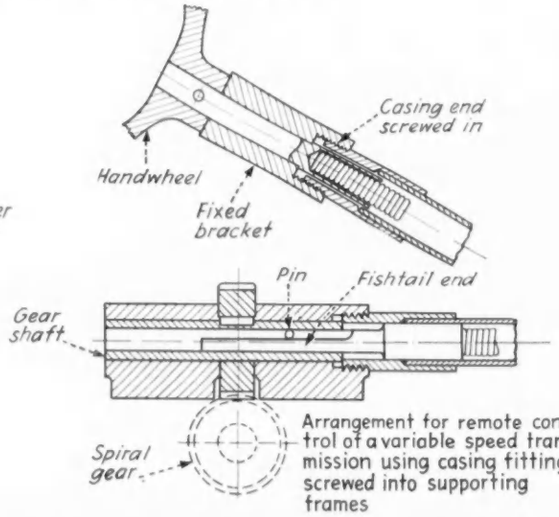
Push-pull and rotary motion is provided in arrangements of this type for winding clocks, resetting counters and for regulating carburetors



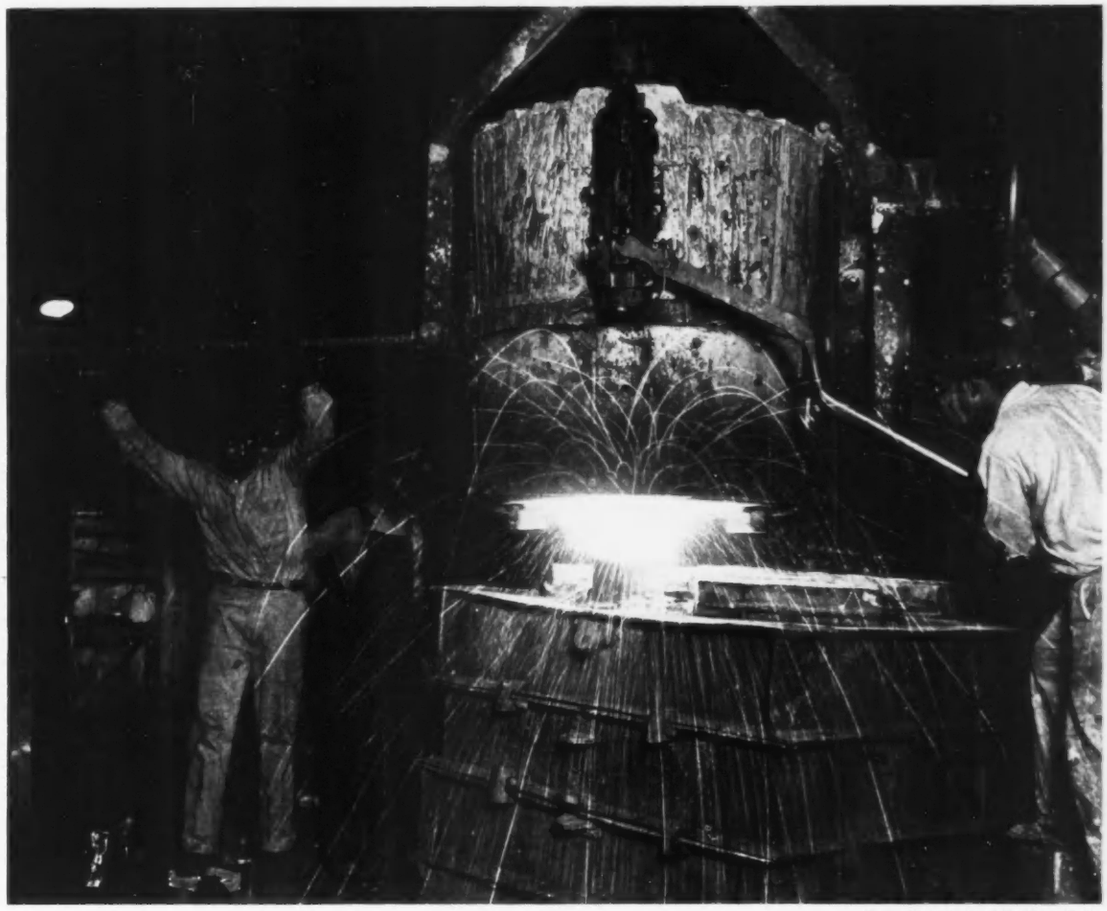
Bell-shaped fittings with set screws couple flexible shaft to rotary switch knob spindle and to multiple-contact switch plate



Fittings are sweated in drilled handwheel shaft and worm shaft in this remote control for positioning a vertical projector



Arrangement for remote control of a variable speed transmission using casing fittings screwed into supporting frames



Texas Electric Steel Castings Company

STEEL CASTING DESIGN

PRESENT DAY DEMANDS for less weight and higher physical properties in parts and structures are resulting in an increasing use of steel castings, to obtain savings in weight without sacrificing ability to stand up under loads, imposed during operation.

Along with the trend toward alloy steels in various lines of structural equipment during the last few years, there has been a very definite increase in the use of alloy steels for pressure parts, especially in the oil refining industry.

These new demands are impressing upon engineers and designers, who make use of cast steel parts, the significance of those well established principles of design which govern the proportioning of sections and the shaping of contours, which it is desirable to observe in the making of sound castings.

To be sure, there are many conditions met with in commercial design which require a deviation from the ideal dictated by good foundry practice. But if the designer is cognizant of this he can compensate for it and then develop a well balanced design. Quality in steel castings can only be obtained by good design and good foundry practice, both of which must be predicated on a knowledge of the metallurgical phenomena that occur in steel when solidifying within the mold.

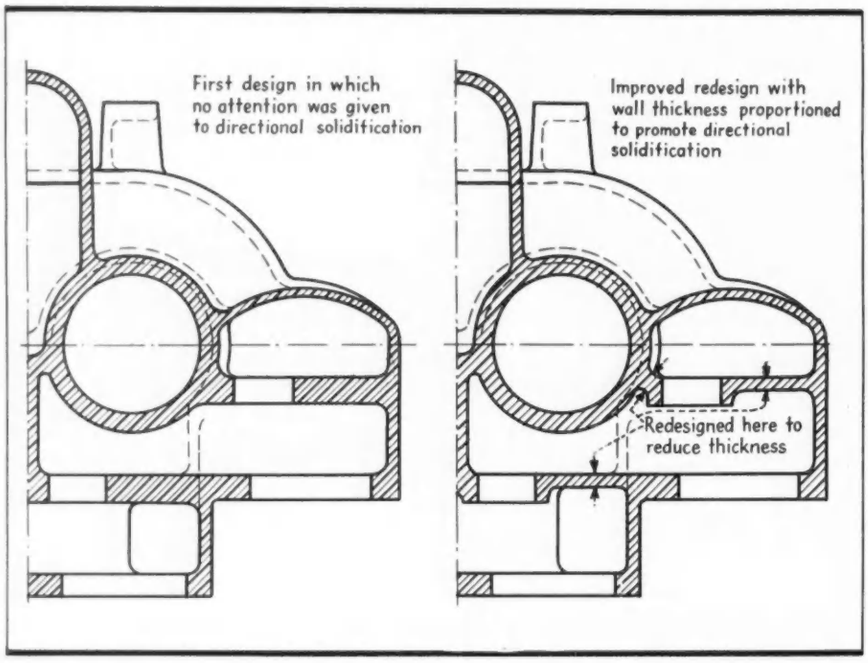
Two well-known basic principles should be kept constantly in mind when designing steel castings: (1) Cross-sections throughout the casting should be as nearly uniform as is feasible; (2) At changes of cross-section and at junction points liberal fillets should be provided. Observance of these rules is essential to develop designs that can be produced as sound castings that will have maximum stability and stress resistance with an economical minimum of deadweight.

These principles recognize the means by which it is desirable to eliminate internal stress in a casting as it is solidifying because of the temperature-contraction relationship. Thus, if hot spots or sections of extra mass are eliminated the excessive temperature changes are eliminated, stresses are reduced and hot tear formation prevented.

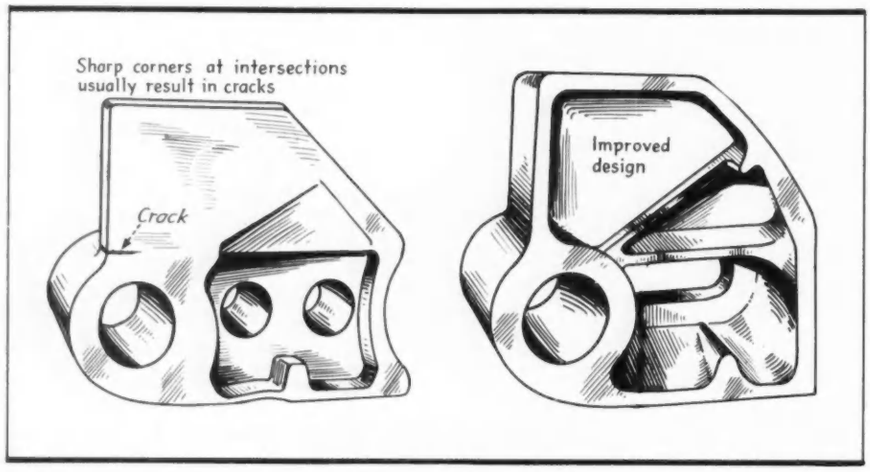
Also, cooling stresses acting upon a casting usually concentrate at abrupt changes in sections or at sharp corners. These positions are structurally weak and coupled with the fact that they are usually hot spots with low physical properties, it is easily seen that they are potential positions of hot tear formation.

Stiffening members such as webs, brackets and ribs between various parts of the casting, to impart rigidity or stiffness, should be kept to a minimum as they are sources of trouble both as to the formation of hot tears and shrinkage cavities. The placing of brackets across joining sections increases the mass effect at the intersection of the adjoining members and the bracket. This undesirable condition may be remedied by extensive coring of the bracket in the region of the adjoining sections. Such coring will not impair the stiffening properties of the bracket and will make for better homogeneity. *(Continued on next page)*

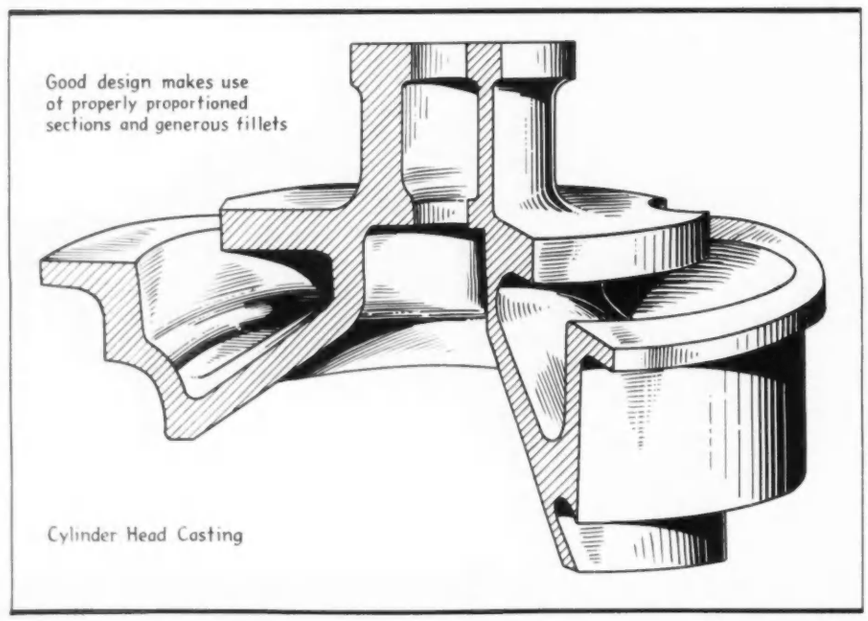
STEEL CASTING DESIGN



Fluid metal in a mold when cooling first solidifies at the surfaces next to the sand, as the still liquid interior cools and contracts it will, if given the opportunity, draw more metal from fluid adjacent sections. If adjacent sections have solidified this feeding can not take place and consequently voids form in the sections to which feeding is stopped. Therefore solidification should progress in sequence from thin sections, which naturally cool and solidify first, to heavier sections. In the first design of the steel casting illustrated some sections are so thin that they would probably solidify before metal could flow or feed to the heavy sections as it is needed to make up for contraction. In the redesign directional solidification has been promoted, by making small concessions in increasing some wall thicknesses and decreasing others.



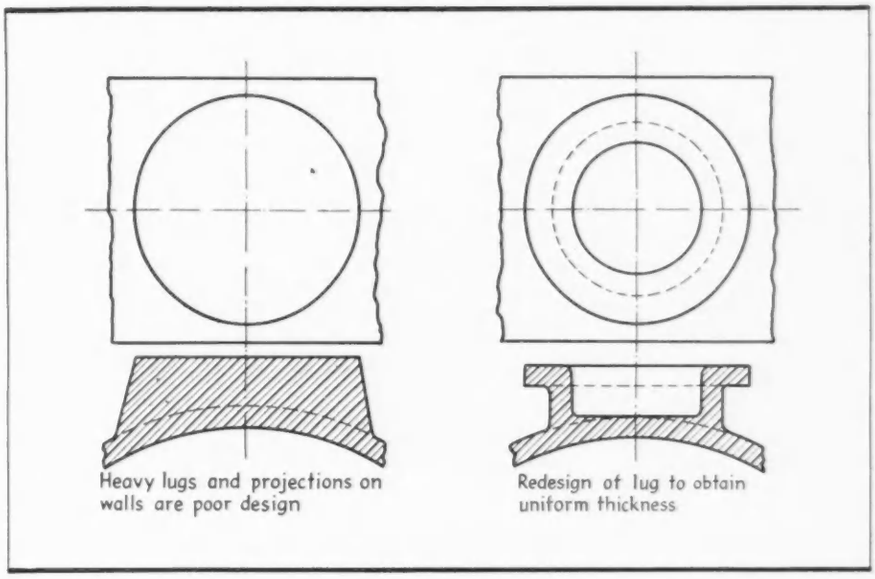
Sharp corners break up the orderly arrangement of the crystalline metal structure especially at the intersections of thin to thick members. They should be always avoided to prevent cracks developing, a typical crack at a sharp corner is indicated by the arrrow. In the redesigned part soundness in the casting is obtained by taking considerable metal out of the hub, by replacing the thin flanged portion with a wall construction of fairly uniform section thickness throughout, and by the generous use of fillets and streamlining.



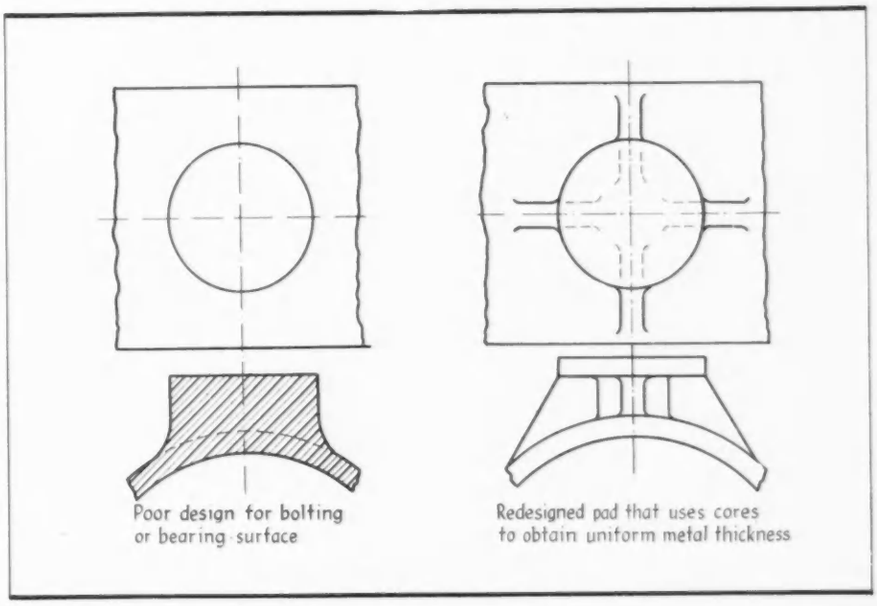
Cylinder head casting with cross-section shown in a cut-away view to illustrate good design practice in proportioning section thicknesses. Changes in thickness of sections are avoided as far as possible and generous fillets are used throughout in order that solidification may proceed from the thinner sections to the heavier sections and then to the head or riser. It is unnecessary that a dependable steel casting have comparable thickness in all its members so long as there is a sweeping and gradually changing connection between those portions that are of unequal thicknesses. For example, liberal radii are used for fillets at member junctions, so as to give the liquid metal an opportunity to solidify directionally by promoting the feeding of metal from heavy sections to thin sections as solidification takes place, and thus avoid shrinkage defects that form when metal contracts because the supply of fluid metal is shut off.

EXAMPLES COURTESY OF AMERICAN FOUNDRYMEN'S ASSOCIATION

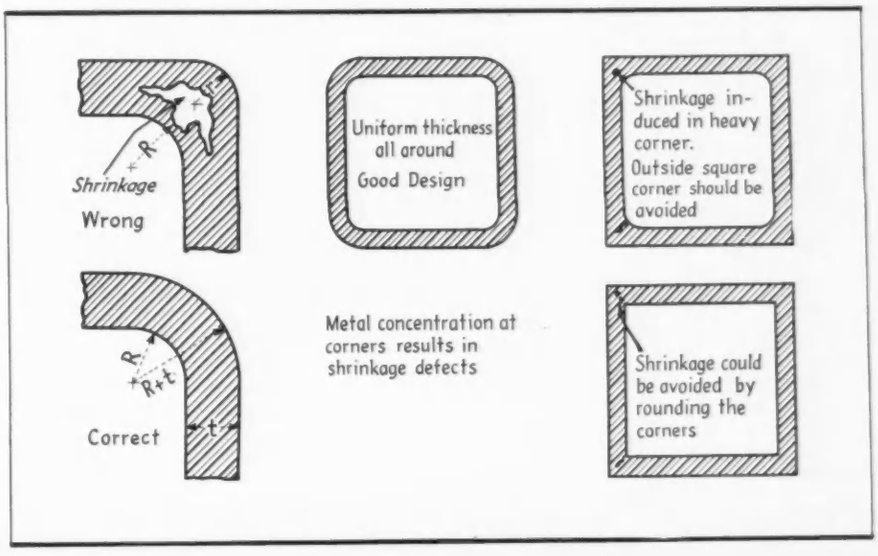
Projections and heavy lugs on cylinders that build up the wall thickness are poor design. A good design of a projection is shown on the right by substituting for the lug a flange supported by a ring. The metallurgical problems incidental to inequalities of cooling stress and of resultant structure are greatly magnified when a part is cast in steel rather than in gray iron. Stress that is produced by contraction necessarily becomes greater because of the characteristics of the metal and the increase in the degree of contraction. The amount of contraction or shrinkage that is typical of gray iron is about half that of steel, mainly because of the greater amount of carbon in gray iron and lower pouring temperature as compared with that of steel.



Reduction in metal thickness can sometimes be accomplished by using a supporting rib construction under a pad or flange as shown in the improved design, in which the strength of the bolting or bearing surface construction is not decreased. Often in engineering construction considerable strength is desired in that portion of the steel casting that constitutes a union between two parts. The sum total of strength and toughness of a union in a well made steel casting is dependent usually on the extent to which the engineer applies the two basic designing principles covering equal sections and generous fillets.



Metal concentrations at corners should be avoided by exercising good judgment in the use of fillets. Corners are sometimes designed with large radii at inside corners and with small radii at the outside to improve the section modulus, but usually all that was expected to be gained in the way of extra strength is more than lost because of poor feeding in such corners after the thinner adjacent walls have solidified. Correct corner design uses a small radius at inside corner with the outside radius struck from same center as the small radius. Sharp outside corner with rounded inside corner or sharp corners inside and out are not conducive to soundness at corner sections. Sharp corners also break up good continuity of the crystalline structure as it forms while solidifying from the liquid steel.



WROUGHT BRASSES AND BRONZES—

Item Number	Material	Composition [1] (per cent)					Ultimate Strength [2] (1,000 lb. per sq. in.)				Yield Strength [2] (1,000 lb. per sq. in.)				Elongation [2] (per cent in 2 in.)				Thermal Conductivity [3] (cal. per sq. cm. per sec. per deg. at 20 deg. C.)	Relative Suitability for Being Worked		Relative Suitability for Welding				Relative Machinability
							Sheet		Rod		Sheet		Rod		Sheet		Rod										
		Copper	Zinc	Tin	Lead	Others	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft		Cold	Hot	Gas	Carbon Arc	Metallic Arc	Resistance	
1	Gilding Metal	95.0	5.0	....	....	....	55	35	....	....	34	11	....	....	5	38	....	....	0.576	A	A	C	B	B	D	20
2	Commercial "Bronze"	90.0	10.0	....	....	....	67	37	....	....	47	11	....	....	3	40	....	....	0.446	A	A	B	B	C	D	20
3	85% Red Brass (Rich Low Brass)	85.0	15.0	....	....	....	75	42	70	42	61	17	50	15	4	43	17.5	45	0.380	A	A	B	B	C	D	30
4	80% Red Brass (Low Brass)	80.0	20.0	....	....	....	75	43	70	45	65	15	60	15	4	50	15	50	0.335	A	B	B	C	D	D	30
5	Shell Head (Brazing or Special Spring Brass)	75.0	25.0	....	....	....	80	47	....	....	60	15	....	....	5	45	....	....	0.310	A	C	B	C	D	D	30
6	Spring Brass	72.0	28.0	....	....	....	76	47	....	....	35	15	....	....	4	55	....	....	0.295	A	C	B	C	D	C	30
7	Seventy-Thirty (Cartridge, Spinning or Eyelet) Brass	70.0 68.0	30.0 32.0	....	....	....	76 78	45 46	....	....	65 50	15	....	....	4 5	50 58	....	....	0.290	A	C	B	C	D	C	30
8	"Two-and-One" Mixture (High, Drawing or Yellow Brass)	67.0 65.0	33.0 35.0	....	....	....	76	45	70	45	....	....	....	12	5	60	15	50	0.285	A	C	B	C	D	C	30
9	Yellow Brass (Extruded Rivet Metal)	63.0	37.0	....	....	....	78	48	70	50	....	....	....	....	4	50	12	50	0.285	B	B	B	C	D	B	40
10	Muntz Metal	60.0	40.0	....	....	....	80	57	70	61	60	19	60	15	9.5	48	15	50	0.300	C	A	B	C	D	B	40
11	*Leaded Brass* Free Cutting or Leaded Commercial "Bronze"	89.0 88.5	9.0 10.0	....	2.0 1.5	....	....	....	60	35	....	....	....	....	....	....	8	30	0.432	B	B	C	C	C	D	90
12	Free Cutting or Leaded Brass	69.0	29.5	....	1.5	....	....	....	65	45	....	....	33	....	....	....	10	34	....	C	D	C	D	C	D	....
13	Free Cutting High Brass (Bearing Brass)	67.0	29.0	....	4.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	C	D	C	D	C	D	100
14	Tube Brass	66.5	33.0	....	0.5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	A	D	B	C	C	D	60
15	Free Cutting Tube (Leaded High, Semi-Leaded, Buff, Matrix) Brass	65.5 64.0	32.75 35.0	....	1.75 1.0	....	80	45	70	45	....	....	....	....	5	60	4	40	....	B	D	B	C	C	D	70
16	Stamping Brass	65.0	34.7	....	0.30	....	....	....	....	....	....	....	....	....	....	....	....	....	....	B	D	B	C	C	C	50
17	Engravers' Brass	63.5	34.5	....	2.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	C	C	C	C	C	D	90
18	Free Cutting Brass (Free Cutting or Riveting and Turning Rod, Clock Brass)	62.0 61.5	34.75 37.0	....	3.25 1.50	....	80	45	62 80	47 45	....	....	45	27	....	....	20 4	60 40	0.258	D	B	C	D	D	D	100
19	Forging Rod	60.0	38.25	....	1.75	....	....	....	70	50	....	....	30	21	....	....	10	45	0.258	D	A	C	D	D	D	80
20	Architectural "Bronze" (Typical)	58.0 56.0	39.0 41.5	....	3.00 2.50	....	70	50	....	....	55	15	....	....	10	20	10	20	....	D	A	C	D	D	D	90
21	*Special Brasses* Silicon Brass	78.0 77.0	20.0 22.0	....	....	2.0 Si 1.0 Si.	110 96	55	....	....	83	12.5	....	....	4 12	61	....	....	....	A	A	A	A	A	A	30
22	Aluminum Brass	76.0	22.0	....	....	2.0 Al	83	62	....	....	75	62	....	....	17	52	....	....	0.24	A	C	B	B	D	B	30
23	Admiralty Brass	71.0	28.0	1.0	....	....	78	45	....	....	....	....	....	....	5	45	....	....	0.263	A	C	B	B	D	C	30
24	Naval Brass	60.0	39.25	0.75	....	....	90	45	75	54	62	24	55	24	4	40	25	50	0.279	C	A	B	C	D	B	30
25	Leaded Naval Brass	60.0	37.75	0.75	1.5	....	....	....	....	55	....	....	....	....	....	....	....	45	0.279	D	B	C	C	D	D	70
26	Die Casting Brass	60.0	37.75	1.0	1.0	0.10 Al 0.15 Si	....	....	55	....	....	....	35	....	....	....	8	....	....	....	....	....	....	....	....	....	....
27	*Bronzes* Special Phosphor Bronzes	98.75 98.2	....	1.2 1.2	....	0.05 P 0.30 P	65	40	....	....	50	15	....	....	4	48	....	....	0.520 0.430	A	B	B	B	B	C	30
28	5% Phosphor Bronze	94.75	....	5.0	....	0.25 P	85	51	....	....	....	20	....	....	7	55	....	....	0.195	A	D	B	B	B	B	30
29	Leaded Phosphor Bronze	93.75	....	5.0	1.0	0.25 P	85	51	....	....	....	....	....	....	7	55	....	....	0.195	B	D	D	D	C	D	50
30	8% Phosphor Bronze	91.75	....	8.0	....	0.25 P	93	60	....	....	....	20	....	....	12	70	....	....	0.150	B	D	B	B	B	A	20
31	Free Cutting Bronze (Bushing)	88.0	4.0	4.0	4.0	....	....	45	65	....	....	....	....	....	....	55	20	....	0.130	C	D	D	D	C	D	100
32	Silicon Bronzes (Typical)	97.75	....	0.25	....	2.0 Si	100	45	110	45	95	22	97	22	10	65	10	65	0.117	....	....	....	....	....	....	....
		96.25	....	0.50	....	3.25 Si	110	60	125	60	100	24	120	24	5	65	10	65	0.086	....	....	....	....	....	....	....
		96.0	1.0	....	....	3.0 Si	93	56	93	....	....	....	....	....	10	65	35	....	0.08	A	A	A	A	A	A	30
33	Leaded Silicon Bronze	95.5	1.0	....	0.5	3.0 Si	....	....	93	....	....	....	....	....	....	....	35	....	0.08	B	C	C	C	B	D	60
34	Aluminum Bronze	95.0	....	....	....	5.0 Al	105	57	....	....	80	24	....	....	5	55	....	....	....	C	B	....	....	....	....	....
35	Manganese Bronze	59.0	39.0	0.75	....	1.25 Fe 0.05 Mn	75	60	....	....	50	15	....	....	5	35	....	....	0.24	D	A	B	C	D	B	30
		57.5	40.45	1.0	....	1.25 Fe 0.05 Mn																				

[1] Compositions given here are only approximate and represent only the major stock types. They are varied by the supplier to suit the individual problem of the designer.

[2] Values are purely nominal as they represent results of tests of 0.040 in. sheet and 1.0 in rod from several sources. Yield point strength is the stress which produces an extension of 0.50 per cent. Change in dimensions, temper or manufacturing limitations will change these figures so that it is important that unusual or new problems be worked out in cooperation with the supplier.

[3] Coefficient applied up to 300 deg. C. Tests were made on rod and reported in Scientific Paper No. 410, U. S. Bu. of Stds. Fabrication characteristics are indicated by A — excellent, B — good, C — fair, D — poor.

PROPERTIES AND APPLICATIONS

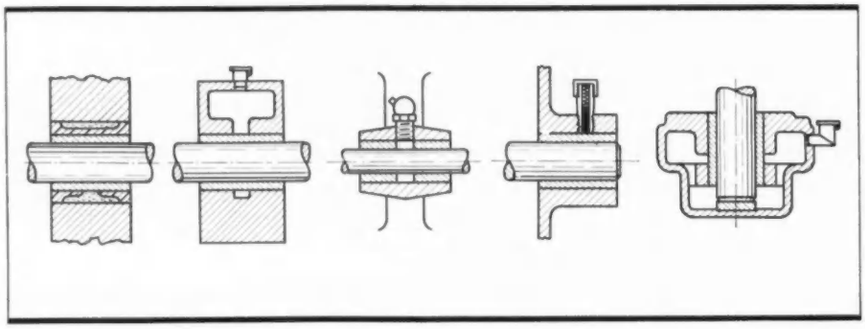
ITEM	MATERIAL	CHIEF CHARACTERISTICS	TYPICAL APPLICATIONS
1	Gilding Metal	High ductility, corrosion resistant, reddish gold color	Drawn, stamped and spun parts, primers, detonators, fuse caps
2	Commercial " Bronze "	High ductility, corrosion resistant	Stamped, drawn, forged and perforated parts, hardware, small shells, screen, screws, rivets, primer caps, kick plates, grillwork
3–4	Red Brass (Rich Low Brass, Low Brass)	Ductility slightly less than first two items, corrosion resistant, yellow colors	Stamped, drawn and formed parts, plumbing pipe, hardware, fasteners, flexible hose, screw shells, condenser tubes, sockets, conduit, radiator cores. The lower copper content material is also used for clock dials and bellows
5–6	Shell Head, Brazing, Special Spring Brass — Spring Brass	Easily brazed or soldered, corrosion resistant, can be cold worked readily, good physical properties for springs	Eyelets, springs, musical instruments, other drawn brazed and spun parts. The lower copper content material is best spring stock and is also used for turbine blades.
7–8–9	" Seventy-Thirty ", Cartridge, Spinning or Eyelet Brass. Lower copper content grades are variously referred to as " Two-and-One " Mixture, High Brass, Spinning or Drawing Brass-Yellow Brass	Can be deep drawn, has high ductility, fair welding properties Lower copper content yellow brass is particularly good for cold heading	Stamped, spun or deep drawn parts, springs, cartridges, eyelets, screw shells, fasteners, bead chain, rivets, radiator tanks, corks and bins, pipe, reflectors. Some of the lower copper content materials also used for parts such as lamp fixtures and other ornamental work such as grilles. Item 9 is used for pins, rivets and screws
10	Muntz Metal (Yellow Metal)	Corrosion resistant (used for ship sheathing) readily worked by hot rolling, extruding or hot-stamping	Valve stems, condenser tubes and heads, brazing rod, architectural trim, perforated metal
11	Free Cutting or Leaded Commercial " Bronze "	Free machining, not suitable for deep drawing	Screw machine products, hardware, forgings, pickling crates
12	Free Cutting or Leaded Brass	Free machining, can be drawn or formed.	For special shapes where a high lead content is detrimental to the bending or working of the part
13–15–17	Free Cutting High Brass (Bearing Brass)—Free Cutting Tube (Leaded High, Semi-Leaded, Butt, Matrix) Brass — Engraver's Brass	Free machining, can be drawn moderately or formed by bending	Screw machine products, threaded parts, bushings, hinges, gears, clock and watch parts, stampings
14–16	Tube Brass — Stamping Brass	Less machinable than above, better workability	Plumbing pipe and fixtures, pump liners, windshield tubing, flashlight shells, special shapes — Stamped, drawn or formed parts, switch plates
18–20	Free Cutting Brass (Free Cutting Rod, Riveting and Turning Rod, Clock Brass) — Forging Rod — Architectural Bronze	Free machining. Item 18 can be cold worked, mills easily. Item 19 can be hot worked readily. Item 20 has strength and hardness	Hardware, screw machine products, pinions, gears, clock and meter parts — forgings, tire valve stems, faucet handles, shower heads — extruded shapes, forgings, hinges, lock bodies
21	Silicon Brass	Low thermal and electrical conductivity, latter makes for good resistance welding. Resistant to corrosion	Special applications where high strength, stamping and electric welding is required, refrigerator evaporator shells, fire-extinguisher shells, hinges, kick plates, springs
22	Aluminum	Resistant to corrosion and erosion	Condenser tubes
23	Admiralty Brass	Resistant to heat and salt-water corrosion	Condenser tubes, tube sheets, ferrules, filter wire
24–25	Naval Brass — Leaded Naval Brass	Resistant to salt-water corrosion. Leaded material can be hot worked	Marine hardware, propeller shafts, bolts, nuts, forgings — valve stems, screw machine products
27–31	Phosphor Bronzes	High strength, good ductility, excellent corrosion resistance, fatigue resistance. Good hot workability up to about two per cent tin and phosphorus. Good cold workability. Leaded types possess fair to excellent machinability characteristics	Welding rod, rivets, screen cloth, springs, wire rope, fasteners, bridge bearing plates, screw machine products. Bearings, bushings, condenser tubes acid resisting uses, thrust washers, diaphragms
32–33	Silicon Bronzes	High strength, resistance to corrosion comparable to copper, non-magnetic, can be readily welded or heat-treated, when leaded possess good machining properties, can be cold worked	Corrosion resistant tanks pressure vessels, pipe fittings, piston rings, piston rod, propeller shaft, filters, condenser tubes, corrugated thermostat tubing, chain, evaporators, forgings, valve gates, bushings, structural shapes, screen wire and cloth transmission line hardware
34	Aluminum Bronze	High strength, resistant to corrosion, rich golden color, ductile	Stampings, condenser tubes, ornamental articles
35	Manganese Bronze	Hard and resistant to wear	Structural purposes, perforated, metals, welded or extruded parts, grille work, screens, wearing parts

"OILLESS" OR SELF-LUBRICATING

TYPE | TYPICAL MOUNTINGS AND FORMS

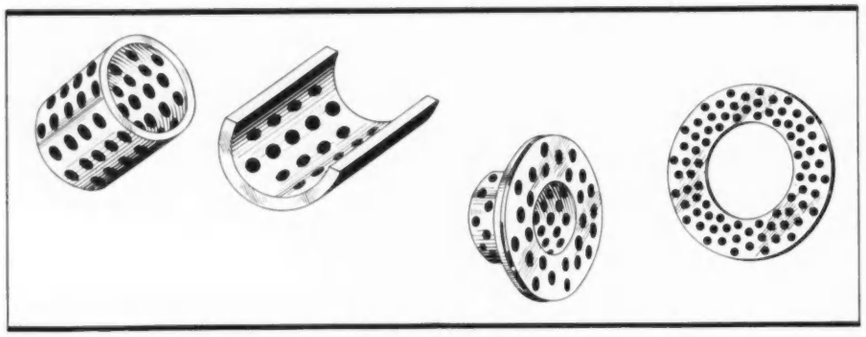
BRONZE—Porous, Powdered Metal, Pressed and Sintered, Lubricant Impregnated

Made of combinations of powdered bronze and graphite with percentage of bronze predominating and impregnated with oil these may be used without additional lubrication for light or ordinary duty. For heavy duty or extraordinary conditions the porosity permits capillary action to draw oil from an oil reservoir surrounding the bushing thus providing continuous added lubrication.



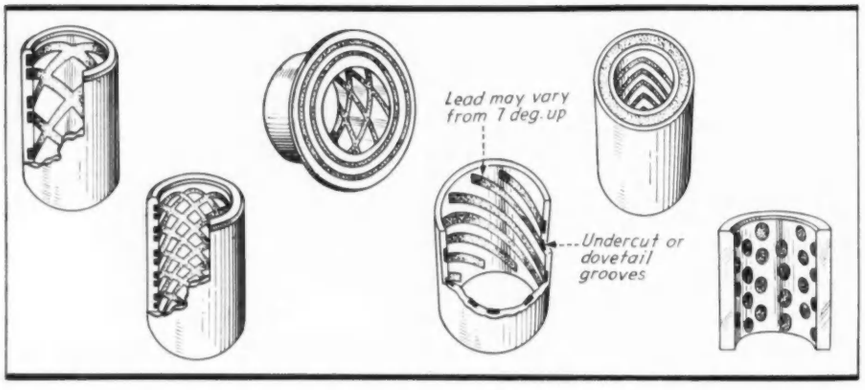
BRONZE—Solid Bushings with Through-Plugs of Graphite

Graphite inserts give self-lubricating properties for long periods of time without requiring additional lubrication. Since graphite plugs extend through bronze bushing an exterior reservoir can be provided for longer life lubrication. These bearings can be used for heavy loads such as exist in derricks, hoists and bridges, are also available in small sizes (down to $\frac{3}{8}$ in.) for light duty machinery.



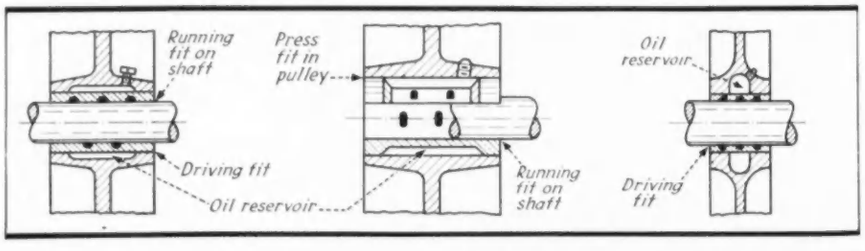
BRONZE—Sand Cast, Bearing Surface Having Graphite Filled Grooves or Holes

With graphite inserts in the holes or grooves, the bearings will operate without other lubricants depending on the type of application. However, with oil or grease lubrication, much longer life can be obtained under heavy loads and high speeds without injury to the shaft or bearing. Size and location of grooves and drilled holes can be varied to give any desired ratio of bronze to graphite area.



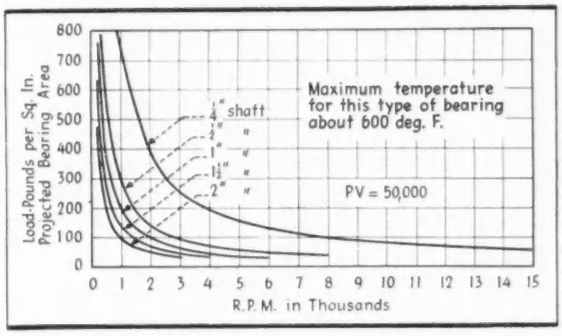
BRONZE—Solid Bushings With Wood Inserts

Wooden pegs inserted through the walls of the bushing draw oil from a reservoir to the bearing surface in small quantities to give proper amount of lubrication.



BEARINGS

LOAD CARRYING CHARACTERISTICS



For ordinary service bearing pressures equal to those used in oiled bearings can be used. For heavy duty:

	Class of Service	Factor (PV) (Speed x Load)	Maximum Shaft Surface Speed	Maximum Bearing Pressure
Continuous	Conservative	15,000	500	1,000
	General	30,000	300	2,000
Intermittent	Bridge-Hydraulic Power Devices, Large Movable Structures.	50,000	100	3,000
	Service Loads, Hoists, Sheaves, Etc.	70,000	100	3,500

SPEED LIMIT, graphite lubricated ..... **50 ft. per min.**
plus oil lubrication **500 ft. per min.**
PV, oil lubrication **15,000**
MAXIMUM PRESSURE ..... **4,000 lb. per sq.in. projected area**
MAXIMUM RUNNING TEMPERATURE ..... **500 deg. F.**

SPEED LIMIT ..... **22,000 r.p.m.**
MAXIMUM PRESSURE ..... **600 lb. per sq.in.**
MAXIMUM RUNNING TEMP ..... **300 deg. F.**

Designed for higher speed operations. The allowable bearing pressure is determined to some extent by the ratio of bronze bearing area to wood area.

MOUNTING TOLERANCES

For ½-in. or smaller outside diameter a press fit allowance of 0.001 to 0.003 in. is sufficient. For larger diameters, clearances should increase up to a maximum of 0.004 to 0.005 in. at 2 in. diameter. Running clearance 0.001 in. minimum is reduced after press fit by approximately 0.6 for wall thicknesses up to $\frac{3}{32}$ in.; for ⅛ to $\frac{3}{16}$ wall thicknesses reduction after press fit will approximate 0.5.

Finished to size with suitable allowances for running or press fits as desired. Length should not be less than 1.5 times shaft diameter. Wall thickness should be at least ten per cent of inside diameter. Under ½ in. inside diameter wall thickness should be 0.125 in. minimum; ½ to ¾ in. diameter, 0.156; ⅞ to 1¼ in. diameter, 0.1875 in. Over 1¼, wall thickness = I.D./16+0.125 (to nearest $\frac{1}{32}$ in.)

Press fit 0.001 to 0.002 in. up to 1 in. outside diameter; 0.002 to 0.003 in. from 1 to 3 in. outside diameter; 0.003 to 0.005 in. above 3 in. outside diameter. Running clearance with graphite lubrication only 0.001 to 0.002 in. greater than plain bronze; with added oil lubrication, from 0.0005 in. up depending on shaft size. Clearance must be enough to avoid metal-to-metal contact at operating temperature.

Clearance for press fit, —0.001 in. per in. diameter. Running clearance should be 0.001 in. up to 2-in. diameter plus 0.003 in. per in. diameter above that. Bearing must be reamed or broached after mounting. Recessed bushings available for walls over 0.25 in. thick.

NOTES

In sizing in place with thin wall bushings, oil flow will be reduced in proportion to sizing. Where running clearance tolerances are to be closer than ±0.001 in., better results can be obtained by diamond boring the bushing after it has been pressed into place. Wax, grease, oil or other lubricant selected to suit service. S.A.E. 40 is commonly used. S.A.E. 10 is used for small diameters and high speed.

Reaming for clearance or alignment reduces efficiency and apparent life. Coefficient of friction varies from 0.04 to 0.07 for heavy loads and approximately 0.09 for light loads. Where pressures require that the bearing area be increased, change length rather than diameter if minimum power loss by friction is desired. These bushings are also available in flanged form and as thrust washers.

It is desirable to ream or precision bore after assembly for proper running fit and alignment. When reservoirs are used, S.A.E. 40 oil is preferred. The reduction in inside diameter after bearings are pressed into place will equal 75 to 100 per cent of press fit allowance depending on wall thickness. Add average press fit to desired running clearance in bore to install bearings without reaming or sizing hole after assembly.

Lubrication is required only a few times per year as bearing will run from two to six months with one filling of the reservoir. These bearings can be furnished in several grades of bronze. Specially treated white pine is used for the plugs.

CONTINUED ON NEXT PAGE

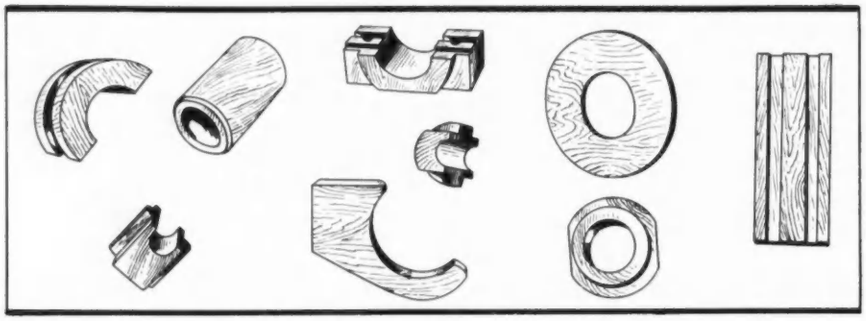
"OILLESS" OR SELF-LUBRICATING BEARINGS

TYPE	TYPICAL MOUNTINGS AND FORMS

WOOD, Impregnated With Lubricant

Lubricated by oil or wax held in pores of hardwood, these bearings may outlast other materials where running loads are light and loads are low particularly if lubricated occasionally. For intermittent service these bearings will retain sufficient lubricant for expected service life of machine.

Lignum Vitae is a special form of wood bearing having a high resin content consisting of a natural gum with pressure resisting quality.



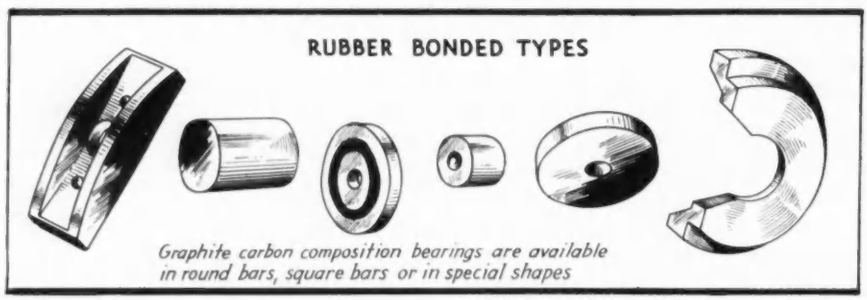
COPPER-Lead, Copper Matte Filled With Amorphous Lead

Amount of lead suspended in the intersizes of the copper matte can be varied to suit lubrication requirements of various speeds and loads.

- Similar to other bearings with no allowance for outside lubrication although this type is also used where the lead serves only as an auxiliary protection when regular lubricant fails.
- Adequate backing must be provided for strength requirements.

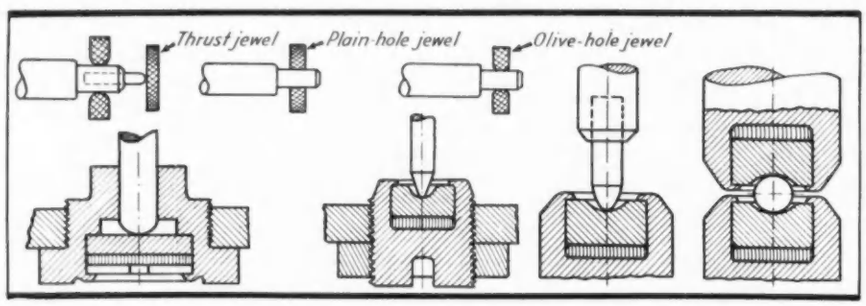
GRAPHITE

Rubber bonded—Lubrication furnished by graphite content, which may amount to 80 per cent. For higher loads and running speeds water can be used; oil is not suitable as it attacks the rubber bond. Special graphite carbon composition—no additional lubricant necessary, resistant to all industrial chemicals. Plain—For bearings operating under light loads, minimum lubrication required.


RUBBER BONDED TYPES
Graphite carbon composition bearings are available in round bars, square bars or in special shapes

JEWELS, Agates, Garnets, Sapphires, Rubies, Diamonds

Use for light loads where hard surfaces with little or no lubrication desired. Shafts should be music wire, hardened drill rod or hardened stainless steel. If lighter weight materials are used for the shafts, steel pins should be inserted at the bearing end. Mineral oil is preferred for lubrication. Creep of the oil can be avoided by dipping the bearings in stearic acid solution.



Phenolic laminated fabric-base bearings, used in marine service, rollneck bearings in steel mills, paper machinery, and deep-well pump bushings, are unaffected by oil, grease, acids, or alkalis. These bearings are generally lubricated by water, but in light duty or intermittent service no lubricant other than resin content is required. Some types require tungsten carbide tools for machining. Bearing forms a smooth, highly-polished surface which prevents scoring of the shaft. Maximum pressure 2,000 lb. per sq. in. of projected area, maximum speed 3,000 ft. per min., and maximum operating temperature 180-300 deg. F. Where mechanical strength can be sacrificed, these bearings can be used for higher temperature service. For mounting and running tolerances, the following formulas will give satisfactory

LOAD CARRYING CHARACTERISTICS	MOUNTING TOLERANCES	NOTES
Speed limit.....300 ft. per min. 3500 r.p.m. Maximum pressure.....100 lb. per sq. in. of projected area Maximum temperature..100–150 deg. F. Dry atmosphere is required for most satisfactory operation. Steam or excessive moisture is detrimental as it causes swelling or warping. Lignum Vitae may be operated up to pressures of 2,000 lb. per sq. in.	Tolerances should be made to suit service as heat generated causes swelling and journals must be fitted with extra clearances for best results. Following values are approximate and may change with extremes of load, speed and temperature: Inside clearance after press fit / Shaft diameter—inside diameter of housing / Oversize for press fit 0.002–0.005 / up to 1/4 in. / ..... 0.003–0.005 / 1/4–7/16 / 0.003–0.005 0.005–0.007 / 7/16–11/16 / 0.005–0.007 0.007–0.009 / 11/16–1.0 / 0.007–0.009 0.009–0.011 / 1 in. and up / 0.009–0.012	These bearings are useful in home appliances or other applications where oil drip is undesirable. Operation is quiet. Grain running at right angles to shaft is most commonly used because end of grain gives more ready lubrication. Self-aligning bearings and other shapes require use along the grain because it is easier to machine in that direction. Lignum Vitae is used on heavier applications also and is claimed to be impervious to water.
Low speed load....2,000 lb. per sq. in. of projected area High speed load....150 lb. per sq. in. of projected area Maximum temp.....1,200 deg. F.	Shaft or journal should have high polish. Bearing bore should be finished to a high degree, especially for high-speed precision service. Particular attention should be given to alignment to avoid concentration of load. Clearance should be = 0.0000063 T (D + 1) where T = working temperature—ambient or room temperature.	Suitable for submerged operation. Easily machined. Useful for sliding and reciprocating bearing surfaces. Should be given coating of light high fire test oil preparatory to running in.
PV factor (wet).....600 PV factor (dry).....200 Maximum temperature.....250 deg. F. Graphite carbon composition is used for low loads or for sliding fits where lubrication and not load-bearing is the important consideration. Limiting speed 20,000 r.p.m., limiting pressure 90 lb. per sq. in. projected area. Limiting temperature 750–800 deg. F.	For rubber-bonded graphite bearings running clearance should be 0.003 to 0.005 in.; thickness of bearing under 3/4-in. inside diameter should be 1/8 in.; over that, 1/4 in. For graphite carbon compositions, running clearance should be 0.002 in. up to 3 in. in diameter, plus 0.0005 in. per in. additional diameter.	Coefficient of friction for rubber-bonded graphite bearings varies between 0.010–0.013 dry and 0.05–0.08 wet. Graphite carbon composition bearings need not be reamed or broached after mounting. Pure graphite is available in rod and washer form. Rods can be used as plungers in dashpots on lighting control mechanisms, scales, blueprint machines where oil might tend to oxidize or become gummy from atmospheric causes.
Glass.....400–500 gr. (not subject to continuous rotation) Sapphires or Rubies.....below 100 gr. (normally) seldom above 500 gr. (30,000–200,000 lb. per sq. in.) Synthetic Sapphires for light loads with no shock Diamond.....carry higher loads than sapphires with better impact toughness and wear resistance	Dimensions for various loads can be calculated according to formulas given in *Product Engineering*, March and May 1934. Size depends on type of shaft end, spherical or conical. Hole end jewel has more friction but carries more load than V-jewel and is usually preferred for radial loads.	Cost depends on size of shaft hole required. Sapphires are generally best although more expensive than other types they are more resistant to wear. While there are other materials just as resistant and harder, sapphires are less brittle and not apt to break as easily. Leather or some other fabric should be used as a cushion in many cases for protection against mounting strains. Oil in such applications as watches and watt-hour meters is essential for long life.

results:

Bore diameter = shaft diameter + 0.04 w + 0.012 for sleeve bearings, where w is bearing wall thickness.

Bore diameter = shaft diameter + 0.007 W + 0.012 for block bearings, where W is the block thickness.

ACKNOWLEDGMENT

The editors wish to acknowledge the generous cooperation of the following companies: Boston Gear Works, Bound Brook Oilless Bearing Co., Bunting Brass and Bronze Co., Continental Diamond Fibre Co., Joseph Dixon Crucible Co., Gatke Corp., General Electric Co., Johnson Bronze Co., Lignum-Vitae Products Corp., Manhattan Rubber Manufacturing Co., Merriman Brothers, Moccasin Bushing Co., Moraine Products Corp., Morganite Brush Co., Neveroil Bearing Co., Nolu Oilless Bearing Co., Oman Metals Co., Randall Graphite Products Corp., Jos. T. Ryerson & Sons, United States Graphite Co., Westinghouse Electric & Manufacturing Co., E. A. Williams & Sons.

WEAR AND ABRASION RESISTANT

WEAR RESISTANCE and abrasion resistance are used interchangeably in the table below as in many cases the problems are the same. Hardness is not the only criterion of good wear or abrasion resistance. Other factors such as toughness of the material, ability to cold work and plasticity all have a bearing on the final answer. For example, rubber because of its ability to "flow" is an excellent wear-resisting material under some conditions. Amount of metal-to-metal contact, unit pressures, lubrication, impact of particles, presence of abrasive, all affect the problem. The solution may be a combination of resistance to rubbing and resistance to cutting by abrasive particles.

TYPE	DESCRIPTION	APPLICATION	NOTES
FINE FINISH			
Lapped **Honed** **Superfinished**	Irregularities are reduced by reciprocating and rotating fine abrasives over the surface of the part to obtain smoothness within 0.000002 to 0.000009 in.	Cylinders, pistons, brake shoes, diesel injector parts, landing gear shock strut parts, camshafts, crankshafts, and wherever it is desirable to reduce initial wear between rotating or reciprocating parts where continued close fit is desirable.	Only useful where metal-to-metal contact is causing wear and then only as an adjunct to properly selected materials. Reduction of irregularities to small dimensions eliminates peaks which would rupture oil film and cause metal-to-metal contact.
HARD FACED			
1. Cobalt — Chromium — Tungsten (such as Stellite) **2. Iron Alloys + Tungsten, Zirconium or Boron (such as Colmony, Stoody)** **3. Metal plus Boride Crystals (such as Colmony No. 1)** **4. Monel** **5. Nickel Borides (such as X-aloy)** **6. Stainless Steel** **7. Tantaloy** **8. Tantalum Carbide** **9. Tungsten Carbides (such as Carboloy, Haystellite)**	Description: Ways in which these hard facings may be applied: furnished as rod materials, Nos. 1 to 6 may be welded on to the parent metal by electric arc or oxy-acetylene flame; cast into the desired shape, all but Nos. 3, 4 and 5 may be brazed or welded on to the parent metal; nickel-borides are the only materials which are cast on, this being a procedure whereby the parent metal is held in a suitable mold while the hard facing material is cast on the outside; spun on overlays are secured by a centrifugal casting process where the parent metal and overlay materials Nos. 1 to 6 and a boron cast-iron alloy are brought up to heat and then spun until cold; metallic boride crystals can be sweated into the parent metal; tungsten carbides may be fused onto the parent metal in an absolutely non-oxidizing atmosphere. Applications: Overlays need not have great strength since they are no more than a protective coating. The welding-on, casting-on, or spinning-in of an overlay has little tendency to alter the physical properties of the parent metal. Care must be exercised in welding-on processes for overlay because of the danger of "puddling" and diluting the overlay metal or the parent metal. At the same time sufficient bond must be obtained to give satisfactory service. The metal plus boride crystal combinations and the iron, cobalt, tungsten, chromium group possess corrosion resistant properties in addition to their wear resistant properties, are useful in food and chemical machinery. Whatever material is used the welding, cast-on or spun-on processes require that relative coefficients of expansion be taken into consideration. Stress relieving after application of the overlay may be required. Cast-on overlays (nickel-borides) may be ground to a high polish and will wear smooth in service. They are all but impervious to the attack of sulphuric, hydrochloric or other acid or aklaline solutions. Centrifugal spinning action eliminates any porosity in the overlay and secures a good bond between the overlay and parent metal. Notes: Several welded-on overlays give varying relations between abrasion and impact properties. Some of them possess excellent red hard properties—important in extreme abrasive conditions. The less hard materials should be used on large surfaces where hair line cracks would be undesirable. Hot shearing and blanking dies, turbine blade shields, valve seats and disks for high-temperature steam and for internal-combustion engines, nozzles for high-head hydraulic turbines, pump casings and impellers, fan housings and coal handling equipment are some of the uses for hard facing materials. They may be applied to cast iron, alloy cast iron, brass, bronze, copper and other non-ferrous alloys as well as most steels. The tungsten carbides and other hard materials such as Tantaloy are welded or brazed into place and used for tools, spray nozzles, and other places where a very hard surface is desired. While stainless steel is not considered by some as a wear-resisting material such hardness as it does have combined with its erosion and corrosion resistance properties has made it useful on turbine blades, sewage disposal and other processing equipment. The cast-on process is applicable to solid shafts of less than 2 in. in diameter and to hollow shafts of any diameter. The solid shafts of large diameters cool so slowly that a quick cooling overlay would be fractured by shrinking stresses. Liquid end rods or plungers for reciprocating pumps, shafts for centrifugal pumps are some typical applications.	

SURFACES

TYPE	DESCRIPTION	APPLICATION	NOTES
	HEAT TREATED		
Surface Hardened **Carburized** **Cyanided**	*Carburizing* and *cyaniding*—adds carbon or carbon plus nitrogen to surface of steel with carbon content below 0.25 per cent giving hardness up to 700 Brinell. Casing secured by packing and heating in carbonaceous materials, gas atmospheres, or liquid depending on depth of case desired. Cyanide and other commercial baths give thin to medium case rapidly.	*Carburizing* and *cyaniding*—gears, cams, shafts and other parts where surface hardness plus core toughness and ductility are desired. Also useful where selective hardening is necessary or where complete hardening is unnecessary. Method used depends on depth of case desired and allowable production time. Cyaniding, for example, gives a thin case rapidly; but since it is a bath process, size of parts is restricted.	Distortion of the part is always a problem with these methods. The higher the temperature of the operation the greater the distortion particularly on parts with thin sections. Carburizing gives any depth of case desired, any hardness; furnace controls size of part.
Nitrided	*Nitriding*—special steels containing aluminum (Nitralloys) are heated in a nitrogen atmosphere to obtain a thin very hard case (up to 1110 Brinell).	*Nitriding*—applied first to airplane engine cylinders gives maximum hardness but may take up to 90 hours to accomplish.	*Nitriding* is carried on at low temperature; distortion is minimized. Thin cases permit use of continuous furnaces with improvement in production quantity.
Ihrigized	*Ihrigizing*—heating iron or steel in presence of silicon carbide and chlorine at high temperatures, adds silicon to surface up to 0.10 in. depth.	*Ihrigizing* was first used on cylinder liners, pump shafts. While low in hardness value it cannot be machined or cut by a saw.	*Ihrigizing* is claimed to absorb oil, and thus to have a self-lubricating property; also possesses resistance to corrosion at high temperatures.
Flame	*Flame*—surfaces of 0.30 to 0.80 carbon steel parts are hardened locally to 400-650 Brinell by heating to critical point with oxy-acetylene flame. Alloy steels such as S.A.E. 3140, 4140 and 4640 and others have been hardened satisfactorily, with depth of case from $\frac{1}{8}$ to $\frac{1}{4}$ in.	*Flame hardening* is useful for bearing areas on large parts which cannot be handled in a furnace. Parts which are satisfactorily treated include: large gear teeth, pads on large rollers, shafts, latheways, paper mill knives and parts made of steels which do not carburize well.	*Flame hardening* is suitable for small quantities, is flexible, rapid and adaptable. Depth of hardness can be controlled from 0.0625 to 0.25 in.
Induction	*Induction*—Surfaces hardened locally by heating with induced current and quenching rapidly. Steels which harden satisfactorily in the medium carbon range can be treated by this method. S.A.E. 1040, 1050, 3140, 4140, and 4340 are some which have been successfully hardened.	*Induction current* gives local selective hardening of surfaces in mass production quantities. Has been applied to crankshafts, camshafts, small parts in business machines.	*Induction hardening* is usually used to produce a hard case on bearing surfaces, especially when local hardening is desired on a number of bearing surfaces on a piece, such as a crankshaft.
Hardened	Where steels are in carbon range above 0.25-0.30 they are heat-treated in atmosphere or liquid bath furnaces to get the desired surface hardness and overall strength, and other properties of steels which carburizing grade steels will not develop.	Applicable to parts of a size which can be handled in furnaces, mass production or small lot, where the steel cannot be carburized, and where greatly increased electric properties and deeper hardness, less creep at elevated temperatures and other properties are desired. For example, the 0.30-0.40 carbon, 12-14 per cent chromium, is used for knives, scrapers and dies where a combination of hardness and corrosion with wear resistance is required.	High carbon stainless steel, chromium 10 to 18 per cent, have hardness and resistance to abrasion, also resist chemical attack. Addition of more chromium improves resistance to oxidation at high temperatures far above those at which carbon steels can be used. Addition of nickel to steel gives toughness, ductility and strength. Manganese in large quantities (10-15 per cent) makes steel unmachinable but gives good wear and abrasion resistance.

CONTINUED ON NEXT PAGE

WEAR AND ABRASION RESISTANT SURFACES

TYPE	DESCRIPTION	APPLICATION	NOTES
Metal Sprayed	Metal spray applies particles of all but extremely high-melting-point metals to any material, metal or non-metal. Metals which can be sprayed include lead, zinc, brass, bronze, nickel silver, monel, stainless or other high carbon steels. Size 0.032 to 0.1875 in. wire is fed through a heating unit in a portable gun. Applied at a comparatively low heat, the metal spray process does not effect any heat treatment.	Surfaces of low cost material can be built up and given fair wearing qualities at low cost after all fabrication processes, rolling, drawing or bending, have been completed. Density of the coating is about 10 per cent less than the solid. This results in a porosity somewhat like that of oilless bearings—an advantage in certain applications.	Spraying with inert gas instead of compressed air reduces porosity. Metal spraying has certain limitations in that electrolysis between dissimilar metals may occur. As in metal overlays, difference in rate of expansion must also be taken into account. Care must be exercised to avoid effects of moisture which may penetrate the pores. To prevent corrosive attacks, a soft metal such as lead or zinc is first sprayed on by an oxy-acetylene torch gun, followed by a coat of hard metal such as stainless steel.
	MATERIALS		
Cast Iron	Cast iron combines low cost and ready machinability with moderately good resistance to abrasion and corrosion from water. When quickly cooled in the casting process, a harder surface—400 to 500 Brinell depending on carbon content—results with improved abrasion resistance. Addition of alloys such as silicon—up to about 14 per cent—adds high resistance to acid attack.	Cast irons are used for cylinder liners, engine blocks, and parts where the combination of fair wear resistance, low cost and convenience of cast shapes is desired.	All the cast irons have the desirable characteristic that they can be cast into intricate shapes without much trouble and are easy to machine. Tensile strengths of 35,000 to 53,000 lb. per sq. in. are attained in some of the alloy cast irons.
Nickel-Chromium Cast Iron (such as Ni-Hard)	Addition of nickel and chromium in chilled or sand castings increases hardness as much as 150 to 250 Brinell numbers above ordinary chilled cast iron.	The much harder nickel-chromium irons have been used for rolls, cement crusher jaws, pug mill knives, pan runner plates, sand and sludge pumps, disk pulverizers, ball mill liners, chute liners, coke crusher segments, sand blast equipment, tumbling barrel parts, conveyor parts. Lower content nickel and chromium containers are being used in machine tool beds and tables, engine parts.	The nickel-chromium cast irons are most often used in a heat-treated condition because of the additional strength and impact resistance which can be achieved with simple stress relief treatment. Tensile strength 55,000 to 80,000 lb. per sq. in. in chilled parts.
Meehanite	A processed cast iron available in a number of different grades including one with abrasion and erosion resistance, another with intense hardness. Hardness in the wear resisting classes ranges from about 200 to 600 Brinell depending on whether chilled, heat treated or sand cast. One grade can be nitrided to give Brinell hardness up to 870.	This type is used for bearing bushings, gears, cams, dies, sheaves, brake drums, sliding members where long life with relatively favorable coefficient of friction is desired. Its maximum hardness is about the same as the manganese steels below.	In Meehanite the deposition of graphite is controlled to give uniform dispersion. Some of the wear resistant grades are readily machinable, others are not. Co-efficient of friction is 0.17 to 0.19 against steel. Tensile strength varies from 38,000 to 75,000 lb. per sq. in. depending on grade.
Manganese Steels (Hadfield type)	If alloy content contains manganese in range of 10-14 per cent, a material results which can be fabricated by casting or forging. It is difficult to machine but combines good shock and abrasion resistance. Addition of nickel to the manganese steels improves toughness, weldability and seems to improve wear resistance above that of the Hadfield type.	Used in sheaves, chain sprockets, pumps, gears, crane wheel buckets, railroad track parts and other parts where severe impact and abrasion are apt to occur in combustion. A manganese-nickel welding rod improves welds in manganese steel—may also be used as a hard facing rod.	Many of the manganese steels are quenched from 1800 deg. F. to give a relatively soft alloy that hardens rapidly when cold worked (from about 200 up to as much as 550 Brinell). It is this property which makes them important abrasion resistant materials. Tensile strengths vary from 80,000 to 140,000 lb. per sq. in. depending on composition and treatment.

TYPE	DESCRIPTION	APPLICATION	NOTES
"S" Monel	Used primarily in the form of castings, although there is some possibility that it might be applied as a hard facing material by gas or electric arc welding. It is hard, as cast, but its hardness and wear resistance are improved by double heat treatment. The first part of the treatment consists of holding castings at 1600 deg. F. for two hours and then allowing to cool in air to 1100-1200 deg. F. and quenching in oil. This gives machinable hardness of 240 Brinell, after which final hardness is attained by heating at 1100 deg. F. for four hours, followed by slow cooling.	This material has good retention of hardness as temperature is increased. It is not particularly suitable for impact abrasion such as are the manganese steels. It is wear resistant in rubbing contact with other metals (gall-resisting), such as Stellite, heat-treated stainless steel, nitrided steels, or against itself. Applications include valve parts, piston rings and bushings operating in sliding contact, seats and disks for globe valves, pump impellers, centrifugal cast liners, soot blower valves, pistons.	Brinell hardness is about 300 to 350. This alloy consists of hard silicides in a softer material and is useful for rubbing areas where the contact will ride on hard silicide areas. It has been used on pump impellers for handling caustic soda containing salt crystals which is a type of flowing abrasion. Ultimate tensile strength about 100,000 lb., yield strength of 80,000 lb. per sq. in.
High Chromium Alloys	High Chromium—25 to 30 per cent with carbon 2.5 per cent—alloys are generally used in the as cast condition.	High chromium iron alloys are used where abrasion is severe but there is little shock such as in mill liner plates, dry pan runner plates, chute linings.	These alloys are generally used in the as-cast condition and where no great strength is required. Brinells usually 145 to 200 although one cast type is available with hardness of 290 to 600, with machinability characteristics fair to good. Ultimate tensile strength varying from 40,000 to 90,000 lb. per sq. in.
Chromium Plated	Chromium coating formed by electrolytic process provides a thin wear and corrosion resistant surface on steels and other materials.	Chromium plating has been applied to engine cylinder barrels and other engine wearing surfaces. However, temperatures of operation should not be too high or its effectiveness is lost.	Chromium plating is thin, brittle and porous; care must be exercised in grinding and honing. Proper processing of the plating is required to avoid lowering the fatigue limit of the unplated parts.
Composite Metals	By special rolling process two metals can be bonded together so that a thin overlay of expensive material protects a heavier supporting layer of low cost material.	Composite metals have long been used for tools where a hard cutting edge with a low cost backing was desired. Should be applicable to many other wear resisting applications.	This method has also been used in combining beryllium and some of its alloys with other less expensive materials.
Porcelain (Ceramics)	Porcelain enamels applied to cast iron, or sometimes used as a molded ceramic part, furnish wear resistance in special cases. Chemical stoneware is a form which is in use in the processing industries.	Porcelain or ceramic guides have been used in some yarn machines. Acid and corrosion resistance combined with wear against abrasives makes it useful in chemical processing, food processing, metal cleaning and finishing and similar operations where combined abrasion and chemical action must be combatted.	When impact and shock loads are apt to be met with in a design using ceramics the manufacturer should be consulted as to the most suitable material.
Rubber	Soft rubber is bonded to or laid on metal to act as a wear resistant liner.	Rubber has been used for lining chutes, sand blast tubes, conveyors, dredging sleeves and suction hose where abrasion effects are enhanced by impact whether caused by gravity, air or water pressure.	Rubber may be used for temperatures up to about 200 deg. F. In chutes it may be used in thickness of ¼ to ½ in. Liability of injury to the rubber is determined by the sharpness of the material, its weight and velocity. When thoroughly wet the rubber surface is lubricated and actual abrasive wear is reduced. It adheres to most metals, has excellent chemical resistance and can be repaired in the field.

FURNACE-BRAZED JOINTS

For details of the brazing process and a comprehensive discussion of its scope and limitations, see the article, "Furnace Brazed Joints and How to Design Them" by Bruce W. Gonser beginning on page 444, December 1936 *P.E.*

GENERAL DESIGN DATA FOR BRAZED JOINTS

Fit Between Parts To Be Joined

Max. clearance 0.003 in.

Min.—tight press fit.

Shear Strength of Copper Brazed Joints

Mild steel

0.003 in. clearance—22,000 lb. per sq. in.
Tight press fit—29,000 lb. per sq. in.

Alloys steels

0.003 in. clearance—30,000 lb. per sq. in.
Tight press fit—50,000 lb. per sq. in.

Materials That Can Be Copper Brazed

Steel, alloy steels, cast iron, copper-nickel alloys, high-melting brasses. (Note: Metals other than low carbon steels usually require special precautions to prevent oxidation. Copper plating is frequently applied to protect the surfaces to be brazed.)

Brazing Alloys Used

Copper for general purposes.

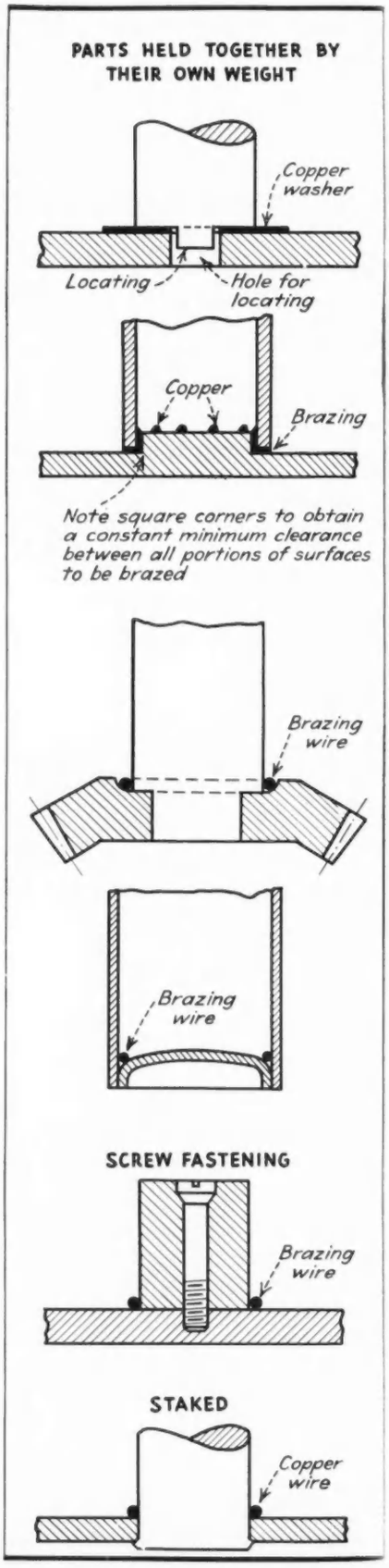
Silver solders for low-temperature brazing. Silver solders give joints about 20 per cent stronger than copper.

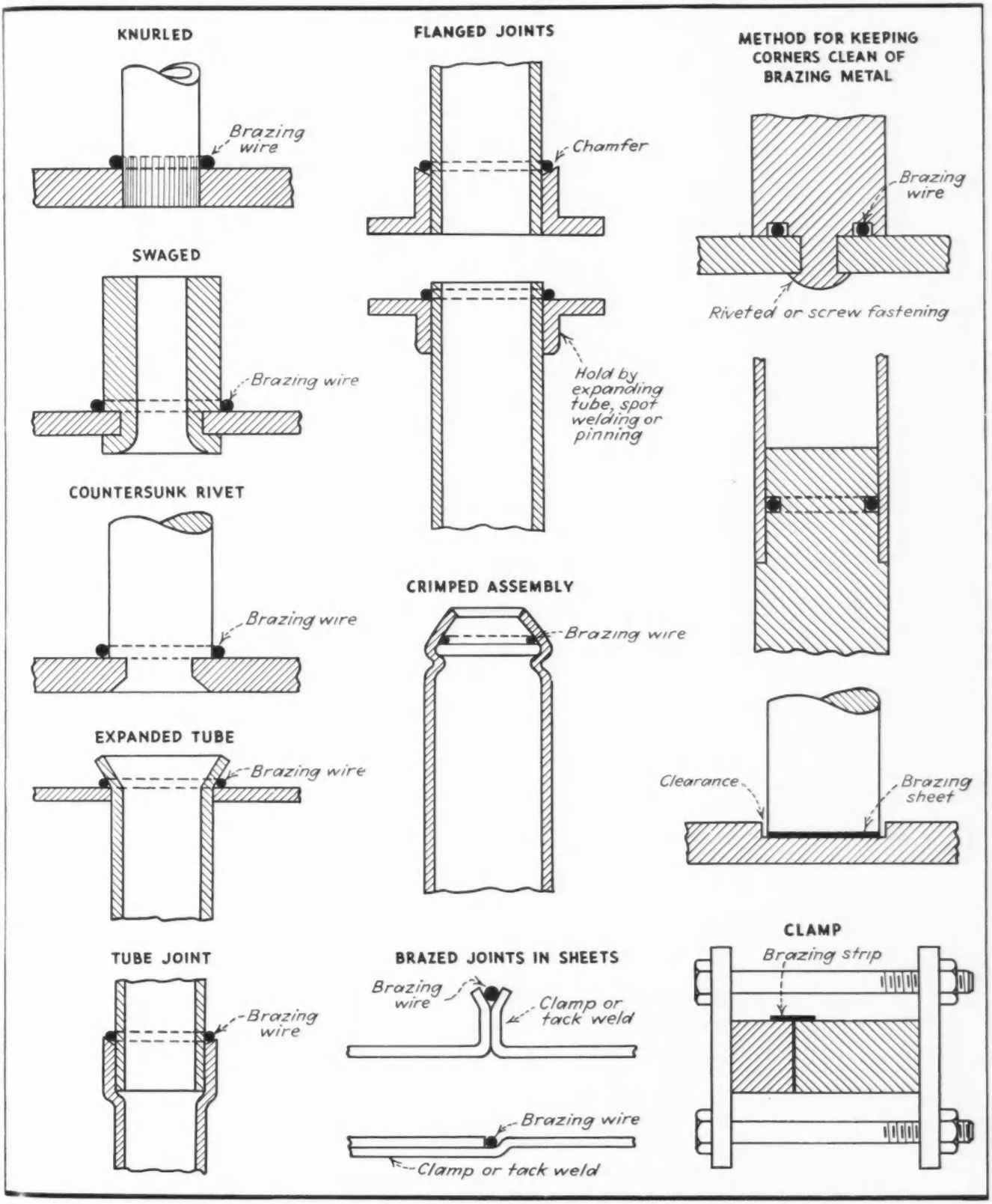
Design Precautions

The brazing metals flow by virtue of capillary attraction but if the gap between the surfaces to be brazed is greater than about 0.005 in., the capillary attraction is destroyed. Therefore, at no point in the path of intended flow of brazing metal should the gap between the surfaces to be brazed be more than about 0.005 in. as this would stop the further penetration of the brazing metal.

Proper support must be given to the pieces when in the brazing furnace in order to avoid sagging. Such support may be incorporated in the design of the part or supporting pieces may be placed under the piece as required when the pieces are put in the brazing furnace.

The design should never be such that the brazing metal must be placed on a flat surface. Under such conditions most of the brazing metal will flow across the surface instead of penetrating the joint.



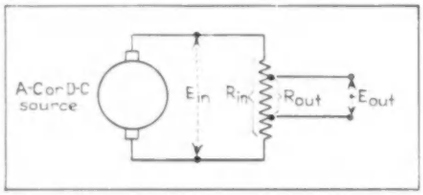


Other methods for holding pieces during brazing include pinning and spot welding. However, these methods are usually more expensive than those shown here

ELECTRICAL CONVERSION SYSTEMS

I. Increasing or decreasing voltage

A. Resistance Voltage Divider—for Use with Constant-Voltage Source, d.c. or a.c.



Conversion relationship:

$$\frac{E_{out}}{E_{in}} = \frac{R_{out}}{R_{in}}$$

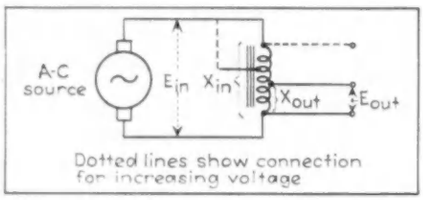
Power losses:

$$W = (E_{in})^2/R_{in} \text{ watts}$$

Can be used only for decreasing voltage below E_{in} value.

Principally useful when the ouput current is of small magnitude. Less efficient than the reactance voltage divider or voltage transformer, but applies equally well to a.c. or d.c. systems. Relationships as given apply only when output current is small compared with current taken by divider itself. Output voltage decreases as output current increases. Power losses increase as output current increases. First cost low for low power applications, but high for heavy output currents.

B. Reactance Voltage Divider—for Use with Constant-Voltage Source, a.c. Only



Conversion relationship:

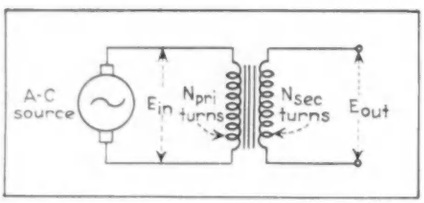
$$\frac{E_{out}}{E_{in}} = \frac{X_{out}}{X_{in}}$$

Power losses:

Depend on size of windings and type of core material. Typical efficiency 50 to 95 per cent, depending on size of unit, at full load.

A special form of transformer, often called autotransformer. Can be used either to increase or decrease voltage. The ratio of reactance X_{out}/X_{in} is in approximately the same ratio as the number of turns included in the respective sections of the winding. Suitable for high or low power applications, but principally useful when power is high. First cost higher than resistance voltage divider, but efficiency higher. As a general rule, power savings justify higher first cost when output power is about one kilowatt or higher.

C. Voltage Transformer—for Use with a.c. Only



Conversion relationship:

$$\frac{E_{out}}{E_{in}} = \frac{N_{sec}}{N_{pri}}$$

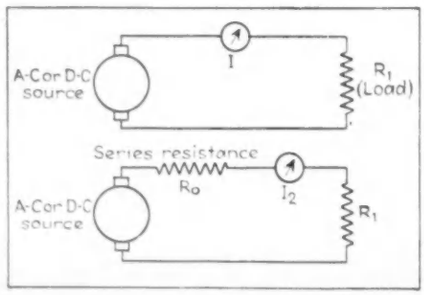
Power losses:

Depend on size of winding and type of core material. Typical efficiency 50 to 95 per cent, depending on size of unit, when fully loaded.

For step-up or step-down purposes. For step-up, secondary winding has more turns than primary. For step-down, opposite is true. Cost and efficiency about same as reactance voltage divider. See note above. Output voltage does down as output current increases, unless power losses are small and regulation of source is good.

II. Increasing or decreasing current

A. Series Resistance for Decreasing Current from Constant-Voltage Source, a.c. or d.c.



Conversion relationship:

$$\frac{I}{I_2} = \frac{R_o + R_1}{R_1}$$

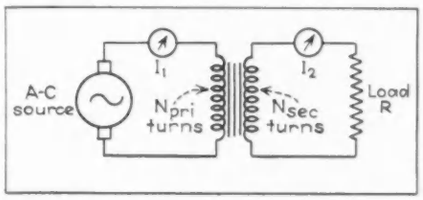
Power losses:

$$W = (I_2)^2 (R_o) \text{ watts}$$

This method decreases current through load by expedient of reducing voltage across load, since part of source voltage is taken across added resistance. Reactance may also be used, with higher efficiency, on a.c. only.

DONALD G. FINK

B. Current Transformer for Increasing or Decreasing Current Through Load, on a.c. Only



Conversion relationship:

$$\frac{I_1}{I_2} = \frac{N_{sec}}{N_{pri}}$$

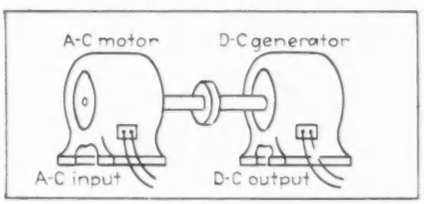
Power losses:

Depend on size of winding and type of core and core material. About same as voltage transformer.

Current transformers usually are of the voltage step-down, equivalent to current step-up, variety with heavy secondary windings. Will pass heavy current through low resistance load with high efficiency and without abnormal strain on supply system.

III. Changing alternating current to direct current (rectifications)

A. Motor-Generator Set.



Conversion relationship:

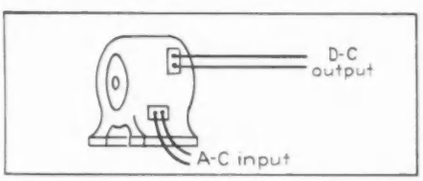
Depends on characteristics and ratings of machines employed. Rated horsepower of motor should equal output rating of generator, plus at least 35 per cent, for full-load running. (1 horsepower = 746 watts.)

Power losses:

Overall efficiency equal to product of efficiencies of the two machines, seldom greater than 50 per cent (70 per cent efficiency in each at full load.

Economical above about one kilowatt.

B. Rotary Converter.



Conversion relationship:

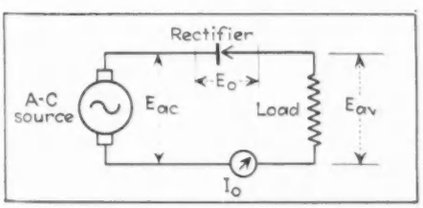
Depends on characteristics of machine, type of winding and design employed.

Power losses:

Somewhat higher efficiency than motor-generator, due to less windage and friction.

Lower first cost than motor-generator, but less flexible. Cost about on par with gas-filled rectifiers, but somewhat less economical and cannot be expanded for increased load.

C. Metallic-Oxide Rectifiers.



Conversion relationship:

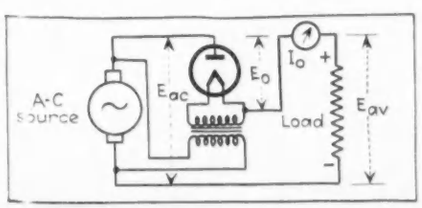
$$E_{av} = 0.45\,E_{ac} - E_o$$

Power losses:

$$W = E_o\,I_o \text{ watts}$$

Useful principally as meter rectifiers, less than 10 milliamp. current, and for low-voltage utility rectification up to 0.5 amp. per sq. in. of oxide surface. Can be air-cooled. E_{av} is average d.c. output voltage, E_{ac} effective input root-mean-square a.c. volts, E_o average d.c. voltage drop across rectifier, I_o effective load current through rectifier. Useful at frequencies up to 5,000 cycles per second, but not higher without loss in efficiency. Should not be used for greater than 25 volts, root-mean-square a.c. input for a single oxide surface. Rectifiers may be used in series for higher voltage operation.

D. High-Vacuum Tube Rectifiers.



Conversion relationship:

$$E_{av} = 0.45\,E_{ac} - E_o$$

Power losses:

$$W = E_o\,I_o \text{ watts}$$

Symbols have same meaning as in description of metallic-oxide rectifiers. Vacuum tube rectifiers are used principally for currents less than 200 milliamperes. Also for very high-voltage rectification above 50,000 volts for X-rays, etc. Widest use as power supply for electron tube circuits, radio receivers.

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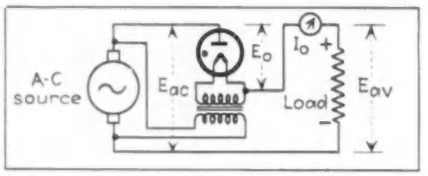
ELECTRICAL CONVERSION SYSTEMS

E. Gas-Filled or Vapor-Filled Tube Rectifiers.



Conversion relationship:

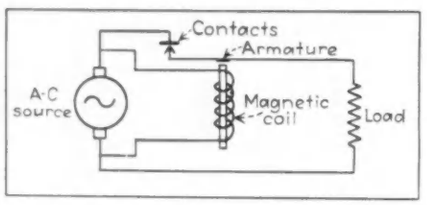
$$E_{av} = 0.45\,E_{ac} - E_o$$

Power losses:

$$W = E_o\,I_o \text{ watts}$$

Symbols have same meaning as in metallic oxide case. E_o is about 15 volts for mercury-vapor filled types, 20 to 40 volts for inert-gas filled types. The rated current capacity of this type of rectifier runs from 0.5 amp. to 75 amp. in glass-envelop types, and up to 5,000 amp. in metal-tank types. Widely used as heavy-duty rectifiers and subway traction converters. For high voltage service, up to 20,000 volts, they are the most efficient rectifier known. For low voltage service, they compete with rotary converters, and are preferred in most modern installations because of higher efficiency, greater flexibility, and great overload capacity.

F. Mechanical Vibrator rectifiers.



Conversion relationship:

$$E_{av} = 0.45\,E_{ac} - E_o$$

Power losses:

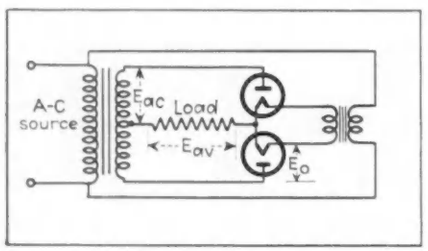
$$W = E_o\,I_o \text{ watts}$$

Used for low current, less than 0.5 ampere peak, applications, when simplicity, portability are essential. Power losses in addition to those stated, include the loss in the magnetic coil. Principal difficulty is deterioration of contact points.

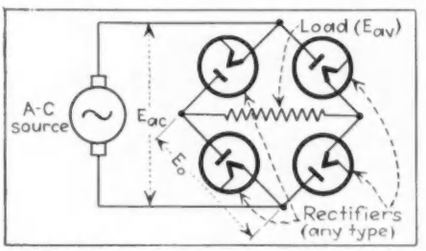
G. Multi-Element Rectifier Circuits.

The above rectifiers, III-A to III-F inclusive, are shown in their simplest form, the half wave rectifier. Each type may be applied in multi-element circuits, in which more than one rectifier element is employed to obtain higher average direct output, smaller percentage of "ripple" voltage in output, and to make use of more efficiency (multiphase) supply.

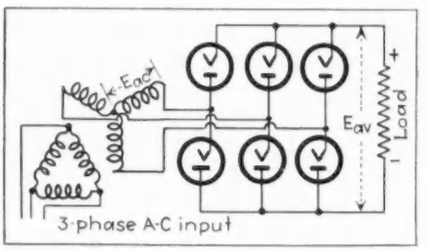
Full wave:
III-G_1
$E_{av} = 0.90\,E_{ac} - E_o$



Bridge type:
III-G_2
$E_{av} = 0.90\,E_{ac} - 2E_o$



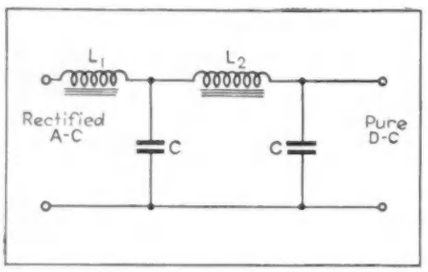
Three-phase full-wave:
III-G_3
$E_{av} = 2.3\,E_{ac} - E_o$



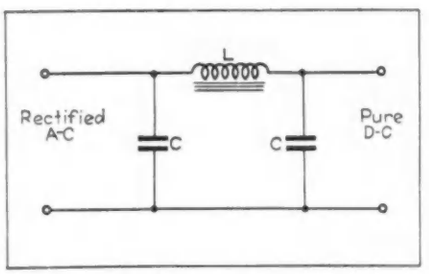
H. Filter (Smoothing) Circuits for Rectifiers.

Used to convert rectified alternating current (output of rectifier circuit) to pure direct current.

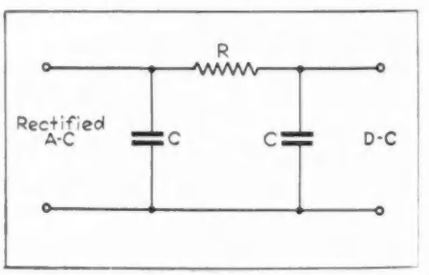
Choke Input



Condenser Output



Resistance-Capacitance

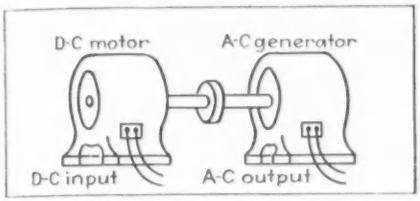


L = inductors C = capacitors

Choke input type insures good voltage and ripple regulation. Condenser input type for maximum output voltage. Resistance capacitance type for low-current, high voltage applications, above 1,000 volts. The LC values (inductance in henries times capacitance in microfarads) are usually between 50 and 300 for 60 cycle rectification. The higher the product, the purer the d.c. obtained.

IV. Changing direct current to alternating current (inversion)

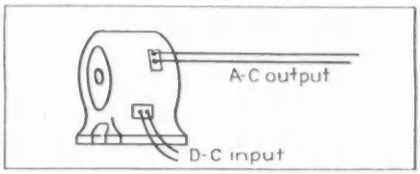
A. Motor-Generator Set (see III-A).



Same remarks apply to use of motor-generator as inverter as for rectification.

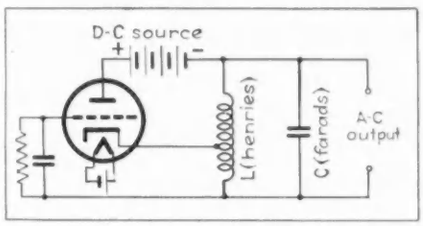
When inverting, the frequency stability depends upon speed-regulation of motor.

B. Rotary Converters.



Same remarks apply as in case III-B. Rotary converters used for inversion are apt to be unstable with respect to varying load current.

C. High-Vacuum Tube Oscillators.



Conversion relationship:

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ cycles per sec.}$$

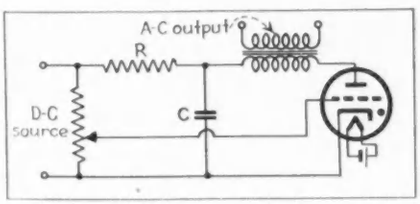
f is frequency of output

Power losses:

Depends on applied voltage, tube characteristics, L/C ratio. Seldom higher than 65 per cent efficient.

Diagram shown is Hartley circuit. Used principally for generating frequencies of 5,000 cycles per sec., and up to 300,000,000 cycles per sec. Low efficiency and cumbersome circuits have prevented use at 60 cycles per sec.

D. Gas-Filled or Vapor-Filled Tube Inverters.



Conversion relationship:

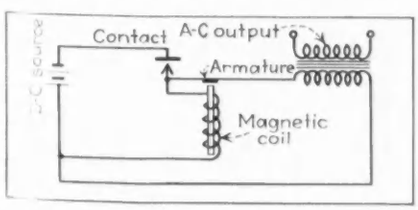
Depends upon R and C values, tube characteristics and applied voltages.

Power losses:

$E_o I_o$ watts for each tube employed, plus losses in supply transformers.

Circuit shown is a simple half-wave inverter. Two-tube full-wave inverters have better output waveform, higher degree of stability, and higher output power. Tube inverters not widely used except experimentally, and for high-voltage inversion purposes, as in direct-current transmission of power. Frequency limited to 5,000 cycles per sec. maximum, in all but smallest sizes of tubes.

E. Mechanical Vibrator Inverters.



Conversion relationship:

Depends upon waveform of output, usually not a sine wave, and contact period vs. open-circuit period.

Power losses:

Efficiency, including output transformer, usually about 50 per cent.

Used with low voltage, high current supplies, such as storage batteries, for obtaining higher voltage alternating current. Widely used as power supply inverters for automobile radio receivers, and in similar low power applications.

DRIVES FOR CONTROLLING TENSION

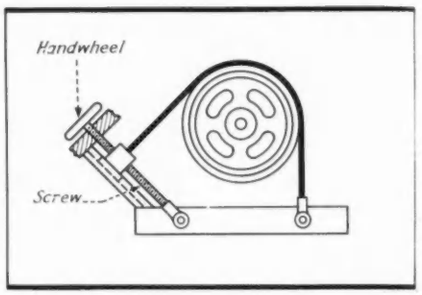
Mechanical, electrical and hydraulic methods for obtaining controlled tension on winding reels and similar drives, or for driving independent units of a machine in synchronism

Mechanical Drives

Band Brake—Used on coil winders, insulation winders and similar applications wherein maintaining the tension within close limits is not required.

Simple and economical but tension will vary considerably. Friction drag at start may be several times that during running by virtue of the difference between coefficient of friction at starting and the coefficient of sliding friction, which latter will also be affected by moisture, foreign matter, and wear of surfaces.

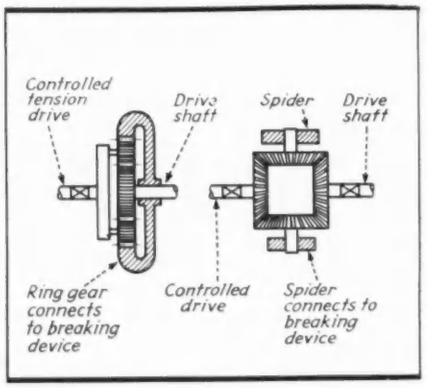
Capacity—limited by the heat radiating capacity of the brake at the maximum permissible running temperature. See article "Temperature Calculations for Clutches and Brakes," by A. C. Rasmussen, page 282, July 1932 P.E.



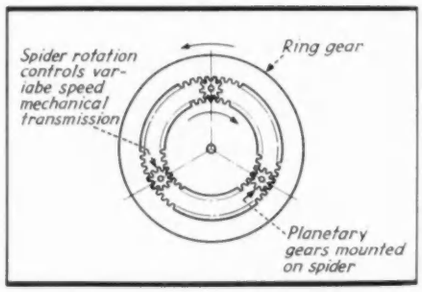
Differential Drives may be of various forms—epicylic spur gears, bevel gear differentials or worm gear differentials.

The braking device on the ring gear or spider may be a band brake, a fan, an impeller, an electric generator or an electric drag such as a copper disk rotating in a powerful magnetic field. A brake will give a drag or tension reasonably constant over a wide speed range. The other braking devices mentioned will exert a torque that will vary widely with speed but will be definite for any given speed of the ring gear or spider. See page 296, August 1937 P.E. for application of a fan to attain constant tension.

A definite advantage of any differential drive is that maximum driving torque can never exceed the torque developed by the braking device.



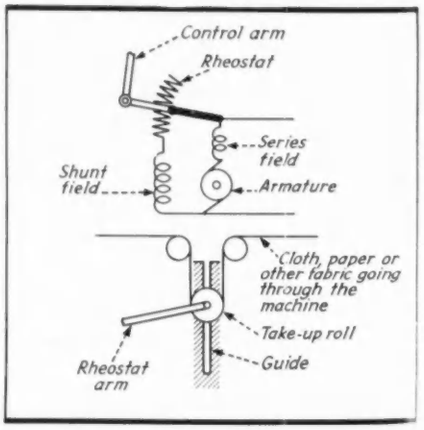
Differential gearing can be used to control a variable-speed transmission. With the ring gear and sun gear driven in opposite directions from the respective shafts to be held in synchronism, the gear train can be designed so that the spider on which the planetary gears are mounted will not rotate when the shafts are running at the desired relative speeds. If one or the other of the shafts speeds ahead, the spider rotates correspondingly. The spider rotation changes the ratio of the variable-speed transmission unit.



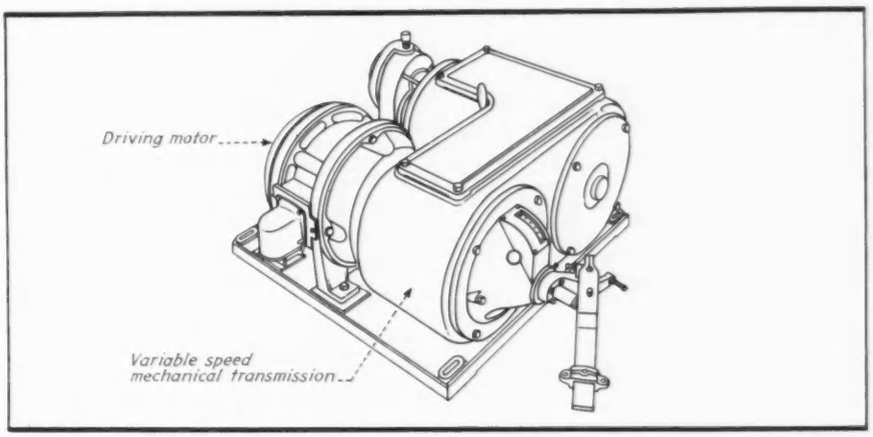
Electrical Drives

Shunt field rheostat in a d.c. motor drive can be used for synchronizing drives. Applied to a machine handling paper, cloth or similar material passing around a take-up roll, movement of the take-up roll moves a control arm that is connected to the rheostat. This type of drive is not suitable to wide changes of speed, above approximately 2½ to 1 ratio.

For wide ranges of speed, the rheostat is put in the shunt field of a d.c. generator which is driven by another motor. The voltage developed by the generator is controlled from zero to full voltage. The generator furnishes the current to the driving motor armature and the fields of the driving motor are separately excited. Thus the motor speed is controlled from zero to maximum. Such a system, popularly called "Ward-Leonard Control" is described in detail on page 204, June 1936 P.E. See also page 228, June 1936 P.E., "Methods of Electric Control—I" by R. S. Elberty, Jr.



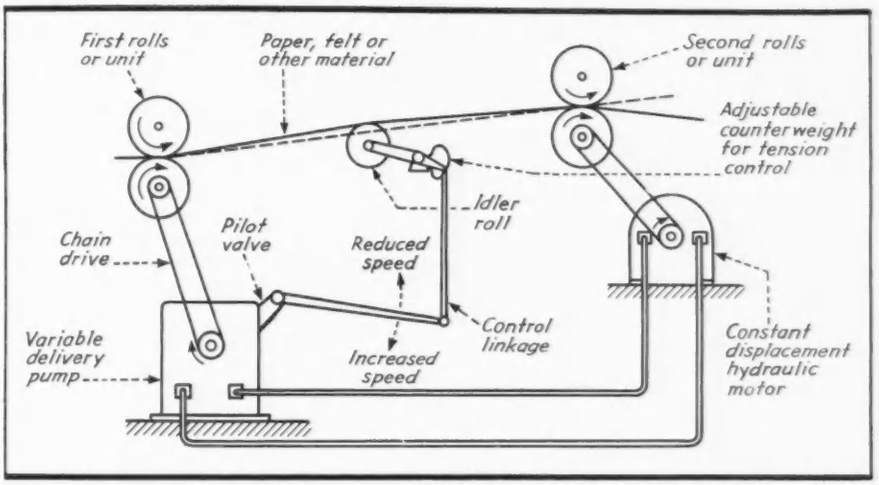
Selsyn motors can be used for direct drive to independent units in exact synchronism, provided inertias are not too great. But regardless of loads and speeds Selsyn motors can be used as the controlling units. As an example, variable-speed mechanical transmission units with built-in Selsyn motors are obtainable for furnishing constant-tension drives or synchronous driving of independent units.



Hydraulic Drives

Hydraulic Control — Tension between successive pairs of rolls, or synchronism between successive units of a machine can be controlled automatically by hydraulic drives. Driving the variable delivery pump off of one of the pairs of rolls automatically maintains an approximately constant relative speed between the two units, at all speeds and loads. The variations caused by oil leakage and similar factors are compensated automatically by the idler roll and linkage which adjusts the pilot valve that controls the displacement of the variable delivery pump.

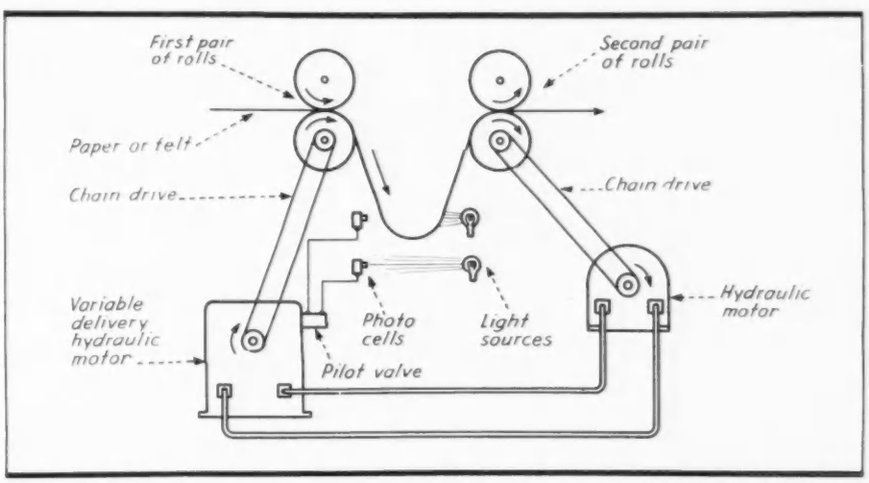
The counterweight on the idler roll is set for the desired tension in the felt, paper or other material. Increased tension resulting from the second pair of rolls going too fast, causes idler roll to be depressed, the control linkage thereby moving pilot valve to cause a decreased pump delivery which slows the speed of the second pair of rolls. The reverse operations take place when the tension in the paper decreases, allowing the idler roll to move upwards.



Courtesy The Oilgear Company

If the material passing through the machine is too weak to operate a mechanical linkage, the desired control can be obtained by photo-electric cells. The hydraulic operation is exactly the same as that described above.

(CONTINUED ON NEXT PAGE)

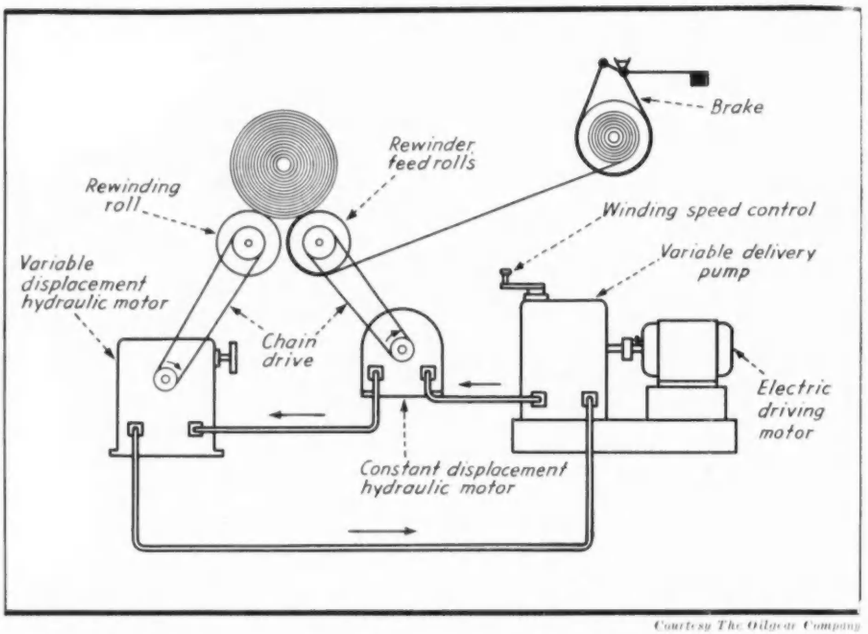


Courtesy The Oilgear Company

DRIVES FOR CONTROLLING TENSION

As mentioned, a band brake used to obtain a friction drag will give variable tension. In this hydraulic drive the winding tension is determined by the difference in torque exerted on the rewinder feed roll and the winding roll. The brake plays no part in establishing the tension.

The constant displacement hydraulic motor and variable displacement hydraulic motor are connected in series with the variable delivery pump. Thus the relative speeds of the two hydraulic motors will always remain substantially the same, the displacement of the variable speed motor being adjusted to an amount slightly greater than the displacement of the constant speed motor, thus tending to give the winding roll a speed slightly greater than the feed roll speed. This determines the tension, because the winding roll cannot go faster than the feed roll, both being in contact with the paper roll being wound. The pressure in the hydraulic line between the constant and variable displacement pump will increase correspondingly to the winding tension. For any setting of the winding speed controller on the variable delivery hydraulic pump the motor speeds are practically constant, hence the surface speed of winding will remain substantially constant, regardless of the diameter of the roll being wound.

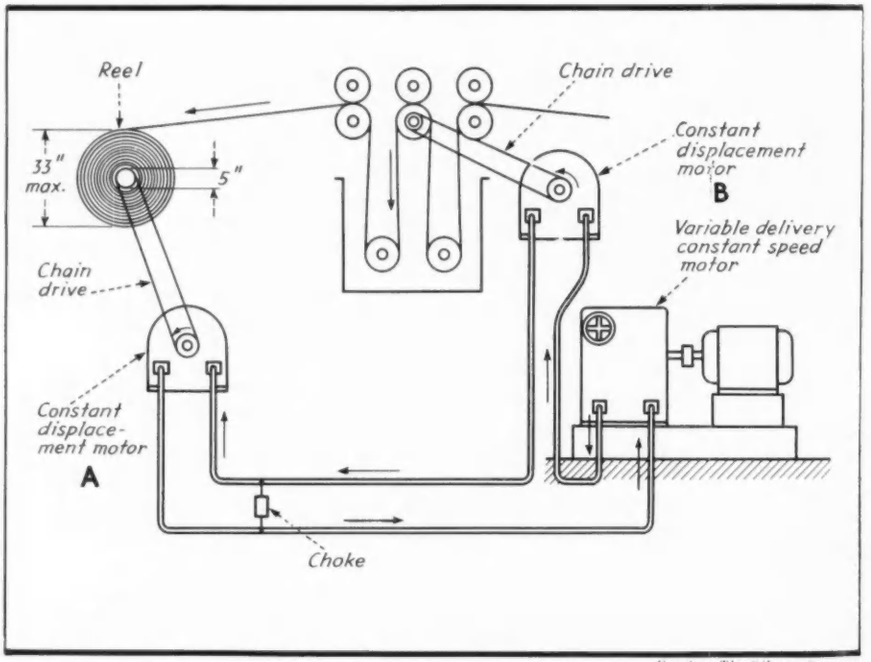


Courtesy The Oilgear Company

Hydraulic drive for fairly constant tension. The variable delivery constant speed pumping unit supplies the oil to two constant displacement motors, one driving the apparatus which carries the fabric through the bath at a constant speed and the other driving the winder. The two motors are in series. Motor *A* driving the winding reel, diameter of which ranges from about 5 in. when the reel is empty to about 33 in. when the reel is full, is geared to the reel so that even when the reel is empty the surface speed of the paper travel will tend to be somewhat faster than the mean rate of paper travel established by motor *B* driving the apparatus. When the reel is empty its speed nearly corresponds to that established by motor *B* driving the apparatus and only a small amount of oil will be by-passed through the choke interposed between the pressure and return line.

When roll is full the r.p.m. of the reel and its driving motor is only about one-seventh of the r.p.m. when the reel is empty. A much greater quantity of oil is forced through the choke when the reel is full because of the increased pressure in the line between the two motors. The pressure in this line increases as the reel diameter increases because the torque resistance encountered by the reel motor will be directly in proportion to the reel diameter, tension being constant. The greater the diameter of the fabric on the reel, the greater will be the torque exerted by the tension in the fabric. The installation is designed so that the torque developed by the motor driving the reel will be inversely proportional to the r.p.m. of the reel. Hence the tension on the fabric will remain at a fairly constant value regardless of the diameter of the reel. This drive is limited to about 3 hp. and is relatively inefficient.

Additional hydraulic circuits will be shown in a forthcoming number.



Courtesy The Oilgear Company

WR^2 OF VARIOUS SHAPED BODIES

Formulas for computing WR^2 of rotating masses by resolving the body into elemental shapes. The method simplifies the calculation of accelerating torques required of the driving motor and the calculation of flywheel effect in critical speed computations. For complete discussion of WR^2 in electric motor selection see the article "*The Significance of WR^2 and How to Calculate It*", *P.E.* October 1934

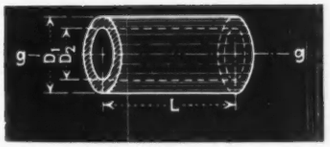
JOSEPH L. SWYERS
Atlas Imperial Diesel Engine Company

1. Weights Per Unit Volume of Materials

MATERIAL	WEIGHT IN LB. PER IN.^{3}
Cast Iron	0.260
Cast Iron (Castings of heavy section i. e., flywheel rims)	0.250
Steel	0.283
Bronze	0.319
Lead	0.410
Copper	0.318

Note: ρ in lb. per cubic in. and dimensions in inches give WR^2 in lb. in.^{2}

2. CYLINDER — About axis lengthwise through the center of gravity



Volume $= \frac{\pi}{4} L (D_1^2 - D_2^2)$

(a) For any material

$$WR^2 = \frac{\pi}{32} \rho L (D_1^4 - D_2^4),$$

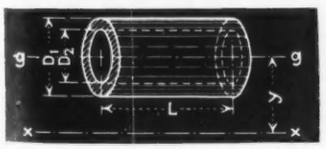
where ρ is the weight per unit volume.

(b) For cast iron $WR^2 = \frac{L (D_1^4 - D_2^4)}{39.2}$

(c) For cast iron (heavy sections) $WR^2 = \frac{L (D_1^4 - D_2^4)}{40.75}$

(d) For steel $WR^2 = \frac{L (D_1^4 - D_2^4)}{36.0}$

3. CYLINDER — About an axis parallel to the axis through center of gravity



Volume $= \frac{\pi}{4} L (D_1^2 - D_2^2)$

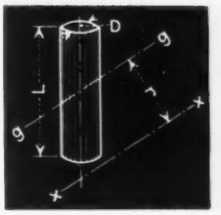
(a) For any material

$$WR^2_{x-x} = \frac{\pi}{4} \rho L (D_1^2 - D_2^2) \left(\frac{D_1^2 + D_2^2}{8} + y^2 \right)$$

(b) For steel

$$WR^2_{x-x} = \frac{(D_1^2 - D_2^2) L}{4.50} \left(\frac{D_1^2 + D_2^2}{8} + y^2 \right)$$

4. SOLID CYLINDER — Rotated about an axis parallel to a line which passes through the center of gravity and is perpendicular to the center line



Volume $= \frac{\pi}{4} D^2 L$

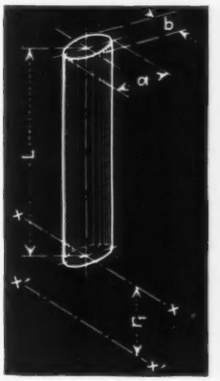
(a) For any material

$$WR^2_{x-x} = \frac{\pi}{4} D^2 L \rho \left(\frac{L^2}{12} + \frac{D^2}{16} + r^2 \right)$$

(b) For steel

$$WR^2_{x-x} = \frac{D^2 L}{4.50} \left(\frac{L^2}{12} + \frac{D^2}{16} + r^2 \right)$$

5. ROD OF RECTANGULAR OR ELLIPTICAL SECTION — Rotated about an axis perpendicular to and passing through the center line



Volume $= K_2 a b L$

For rectangular cross-sections

$K_1 = \frac{1}{12}$; $K_2 = 1.$

For elliptical cross-sections

$K_1 = \frac{\pi}{64}$; $K_2 = \frac{\pi}{4}$

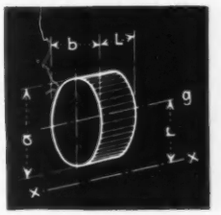
(a) For any material

$$WR^2_{x'-x'} = \rho a b L \times \left\{ K_2 \left[\frac{L^2}{3} + r_1 (r_1 + L) \right] + K_1 a^2 \right\}$$

(b) For a cast iron rod of elliptical section ($\rho = 0.260$)

$$WR^2_{x'-x'} = \frac{a b L}{4.90} \left[\frac{L^2}{3} + r_1 (r_1 + L) + \frac{a^2}{16} \right]$$

6. ELLIPTICAL CYLINDER — About an axis parallel to the axis through the center of gravity



Volume $= \frac{\pi}{4} a b L$

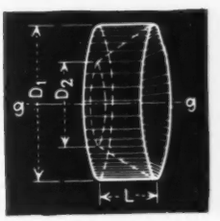
(a) For any material

$$WR^2_{x-x} = \rho \frac{\pi}{4} a b L \left(\frac{a^2 + b^2}{16} + r^2 \right)$$

(b) For steel

$$WR^2_{x-x} = \frac{a b L}{4.50} \left(\frac{a^2 + b^2}{16} + r^2 \right)$$

7. CYLINDER — With frustum of a cone removed

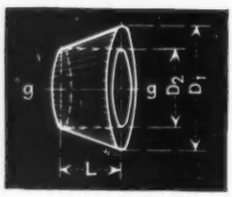


Volume $= \frac{\pi L}{2 (D_1 - D_2)} \times \left[\frac{1}{3} (D_1^3 - D_2^3) - \frac{D_2}{2} (D_1^2 - D_2^2) \right]$

$$WR^2_{y-y} = \frac{\pi \rho L}{8 (D_1 - D_2)} \times \left[\frac{1}{5} (D_1^5 - D_2^5) - \frac{D_2}{4} (D_1^4 - D_2^4) \right]$$

CONTINUED ON NEXT PAGE

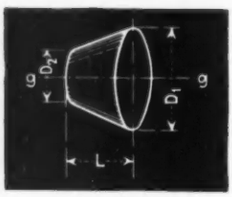
8. FRUSTUM OF A CONE — With a cylinder removed



$$\text{Volume} = \frac{\pi L}{2\,(D_1 - D_2)} \times \left[\frac{D_1}{2}(D_1^2 - D_2^2) - \frac{1}{3}(D_1^3 - D_2^3)\right]$$

$$WR^2_{g-g} = \frac{\pi\,\rho\,L}{8\,(D_1 - D_2)} \times \left[\frac{D_1}{4}(D_1^4 - D_2^4) - \frac{1}{5}(D_1^5 - D_2^5)\right]$$

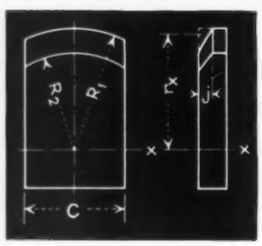
9. SOLID FRUSTUM OF A CONE



$$\text{Volume} = \frac{\pi L}{12}\,\frac{(D_1^3 - D_2^3)}{(D_1 - D_2)}$$

$$WR^2_{g-g} = \frac{\pi\,\rho\,L}{160}\,\frac{(D_1^5 - D_2^5)}{(D_1 - D_2)}$$

10. CHAMFER — Cut from rectangular prism having one end turned about a center



Distance to center of gravity

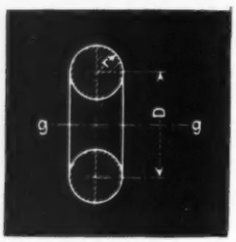
$$r_x = \frac{j R_1^3 B}{\text{Vol.} \times (1 - A)}\left[\frac{1}{3}(A^3 - 3A + 2) + \frac{B^2}{3}(1 - A - A\log_e\frac{1}{A}) + \frac{3}{40}\frac{B^4}{A}(A^2 - 2A + 1) + \frac{5}{672}\frac{B^6}{A^3}(3A^4 - 4A^3 + 1)\ldots\right]$$

$$\text{Volume} = \frac{j R_1^2 B}{(1 - A)}\left\{(A^2 - 2A + 1) + \frac{B^2}{3}\left[\log_e\frac{1}{A} - (1 - A)\right] + \frac{1}{10}\frac{B^4}{A^2}(2A^3 - 3A + 1) + \frac{1}{224}\frac{B^6}{A^4}(14A^5 - 5A^4 + 1) + \ldots\right\},$$

where $A = \dfrac{R_2}{R_1}$; $B = \dfrac{C}{2\,R_1}$.

$$WR^2_{x-x} = -\frac{\rho\, j R_1^4 B}{6\,(1 - A)}\left\{(A^4 - 4A + 3) + B^2(A^2 - 2A + 1) + \frac{9}{10}B^4\left[\log_e\frac{1}{A} - (1 - A)\right] + \frac{5}{56}\frac{B^6}{A^2}(2A^3 - 3A^2 + 1) + \ldots\right\}$$

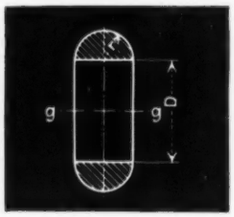
11. COMPLETE TORUS



$$\text{Volume} = \pi^2 D r^2$$

$$WR^2_{g-g} = \frac{\pi^2\,\rho\,D\,r^2}{4}(D^2 + 3r^2)$$

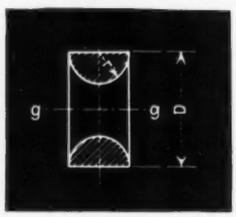
12. OUTSIDE PART OF A TORUS



$$\text{Volume} = 2\pi r^2\left(\frac{\pi D}{4} + \frac{2}{3}r\right)$$

$$WR^2_{g-g} = \pi\,\rho\,r^2 \times \left[\frac{D^2}{4}\left(\frac{\pi D}{2} + 4r\right) + r^2\left(\frac{3\pi}{8}D + \frac{8}{15}r\right)\right]$$

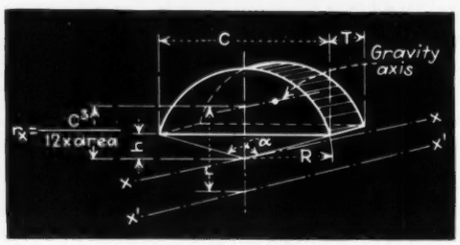
13. INSIDE PART OF A TORUS



$$\text{Volume} = 2\pi r^2\left(\frac{\pi D}{4} - \frac{2}{3}r\right)$$

$$WR^2_{g-g} = \pi\,\rho\,r^2 \times \left[\frac{D^2}{4}\left(\frac{\pi D}{2} - 4r\right) + r^2\left(\frac{3\pi}{8}D - \frac{8}{15}r\right)\right]$$

14. CIRCULAR SEGMENT — About an axis through center of circle



$$\alpha = 2\sin^{-1}\frac{C}{2R}\,\text{deg.}$$

$$\text{Area} = \frac{R^2\alpha}{114.59} - \frac{C}{2}\sqrt{R^2 - \frac{C^2}{4}}$$

(a) Any material

$$WR^2_{x-x} = \rho\, T\left[\frac{R^4\alpha}{229.2} - \frac{1}{6}\left(3R^2 - \frac{C^2}{2}\right)\frac{C}{2}\sqrt{R^2 - \frac{C^2}{4}}\right]$$

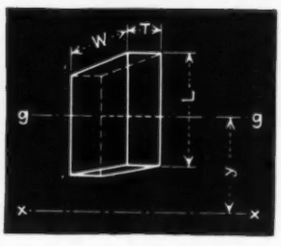
(b) For steel

$$WR^2_{x-x} = \frac{T}{3.531}\left[\frac{R^4\alpha}{229.2} - \frac{1}{6}\left(3R^2 - \frac{C^2}{2}\right)\frac{C}{2}\sqrt{R^2 - \frac{C^2}{4}}\right]$$

15. CIRCULAR SEGMENT — About any axis parallel to an axis through the center of the circles (Refer to 14 for figure)

$$WR^2_{x'-x'} = WR^2_{x-x} + \text{weight}\,(r^2 - r_x^2)$$

16. RECTANGULAR PRISM — About an axis parallel to the axis through the center of gravity



$$\text{Volume} = WLT$$

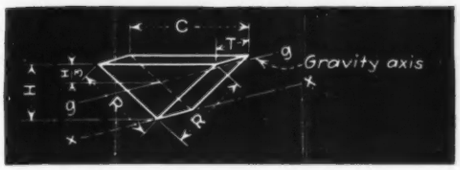
(a) For any material

$$WR^2_{x-x} = \rho WLT\left(\frac{W^2 + L^2}{12} + y^2\right)$$

(b) For steel

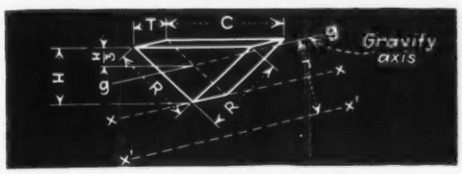
$$WR^2_{x-x} = \frac{WLT}{3.531}\left(\frac{W^2 + L^2}{12} + y^2\right)$$

17. ISOSCELES TRIANGULAR PRISM — Rotated about an axis through its vertex



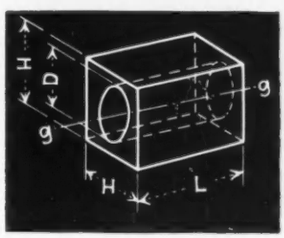
$$\text{Volume} = \frac{CHT}{2} \qquad WR^2_{x-x} = \frac{\rho CHT}{2}\left(\frac{R^2}{2} - \frac{C^2}{12}\right)$$

18. ISOSCELES TRIANGULAR PRISM — Rotated about any axis parallel to an axis through the vertex



$$\text{Volume} = \frac{CHT}{2} \qquad WR^2_{x'-x'} = \frac{\rho CHT}{2}\left(\frac{R^2}{2} - \frac{C^2}{12} - \frac{4}{9}H^2 + r^2\right)$$

19. PRISM WITH SQUARE CROSS-SECTION AND CYLINDER REMOVED — Along axis through center of gravity of square



$$\text{Volume} = L\left(H^2 - \frac{\pi D^2}{4}\right)$$

$$WR^2_{g-g} = \frac{\pi \rho L}{32}(1.697\,H^4 - D^4)$$

20. ANY BODY — About an axis parallel to the gravity axis when WR^2 about the gravity axis is known

$$WR^2_{x-x} = WR^2_{g-g} + \text{weight} \times r^2$$

21. WR^2 OF A CONNECTING ROD — Effective at the cylinder center line, about the crankshaft center line

$$WR^2 = r^2\left[W_1 + W_2\left(\frac{1}{2} + \frac{r^2}{8\,L^2}\right)\right],$$

where: r is the crank radius

L is the center to center length of connecting rod

W_1 is the weight of the lower or rotating part of the rod $= \dfrac{W_R\,(L - L_1)}{L}$

W_2 is the weight of the upper or reciprocating part of the rod $= \dfrac{W_R\,L_1}{L}$

$W_R = W_1 + W_2$, the weight of the complete rod

L_1 is the distance from the center line of the crankpin to the center of gravity of the connecting rod

22. WR^2 OF A PISTON — Effective at the cylinder center line, about the crankshaft center line

$$WR^2 = r^2\,W_p\left(\frac{1}{2} + \frac{r^2}{8\,L^2}\right)$$

where: r is the crank radius

L is the center to center length of connecting rod

W_p is the weight of complete piston, rings and pin

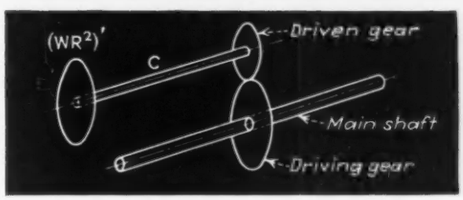
23. MASS GEARED TO A SHAFT

The equivalent flywheel effect at the shaft in question is $WR^2 = h^2\,(WR^2)'$,

where: h is the gear ratio $= \dfrac{\text{r.p.m. of mass geared to shaft}}{\text{r.p.m. of shaft}}$

$(WR^2)'$ is the flywheel effect of the body in question about its own axis of rotation.

24. MASS GEARED TO MAIN SHAFT AND CONNECTED BY A FLEXIBLE SHAFT



The effect of the mass $(WR^2)'$ at the position of the driving gear on the main shaft is

$$WR_2 = \frac{h^2\,(WR^2)'}{1 - \dfrac{(WR^2)'\,f^2}{9.775\,C}}$$

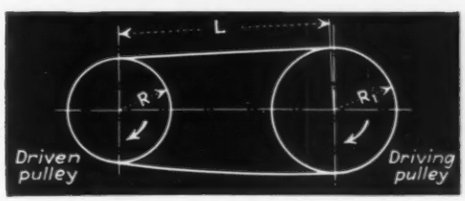
where: h = gear ratio $= \dfrac{\text{r.p.m. of driven gear}}{\text{r.p.m. of driving gear}}$

$(WR^2)'$ is the flywheel effect of geared on mass

f is natural torsional frequency of the shafting system, in vibrations per sec.

C is the torsional rigidity of flexible connecting shaft in lb. in. per radian

25. BELTED DRIVES



The equivalent flywheel effect of the driven mass at the driving shaft is *(see next page for formula)*

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$$WR^2 = \frac{h^2 (WR^2)'}{1 - \dfrac{(WR^2)' f^2}{9.775\, C}}$$

where: $h = \dfrac{R_1}{R} = \dfrac{\text{r.p.m. of pulley belted to shaft}}{\text{r.p.m. of shaft}}$

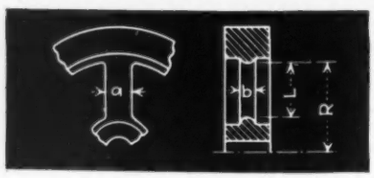
$(WR^2)'$ is the flywheel effect of the driven body about its own axis of rotation

f is the natural torsional frequency of the system in vibrations per sec.

$C = \dfrac{R^2\, A\, E}{L}$, where

A = cross-sectional area of belt in sq. in.
E = modulus of elasticity of belt material in tension, lb. per sq. in.
R = radius of driven pulley in in.
L = length of tight part of belt which is clear of the pulleys in in.

26. EFFECT OF THE FLEXIBILITY of flywheel spokes on WR^2 of rim.



The effective WR^2 of the rim is

$$WR^2 = \frac{(WR^2)'}{1 - \dfrac{(WR^2)' f^2}{9.775\, C}}$$

where: $(WR^2)'$ is the flywheel effect of the rim

f is natural torsional frequency of the system of which the flywheel is a member, in vibrations per sec.

C is the torque required to move the rim through one radian relative to the hub

$$C = \frac{12\, g\, E\, k\, a^3\, b\, R}{L^2}\left(\frac{L}{3R} + \frac{R}{L} - 1\right)$$

where: g is the number of spokes.

E is bending modulus of elacticity of the spoke material,

$k = \dfrac{\pi}{64}$ for elliptical, and $k = \dfrac{1}{12}$ for rectangular section spokes.

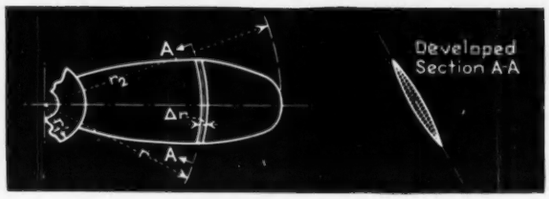
All dimensions are in inches.

For cast iron spokes of elliptical section ($E = 15 \times 10^6$ lb. per sq. in.)

$$C = \frac{g\, a^3\, b\, R \times 10^6}{0.1132\, L^2}\left(\frac{L}{3R} + \frac{R}{L} - 1\right) \quad \frac{\text{lb. in.}}{\text{radians}}.$$

Note: It is found by comparative calculations that with spokes of moderate taper very little error is involved in assuming the spoke to be straight and using cross-section at midpoint for area calculation.

27. BLADE OF A MARINE PROPELLER



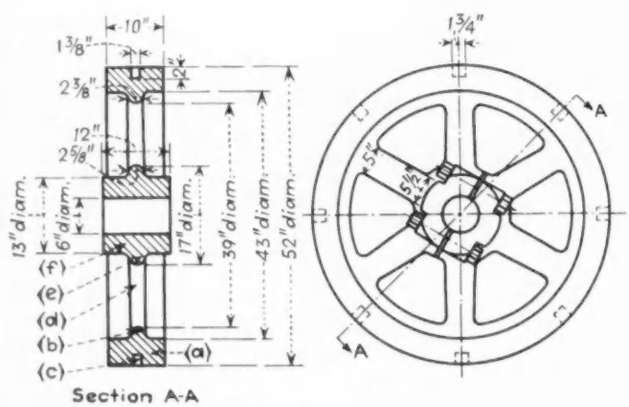
The blade is divided from r_1 to r_2 radially into "n" segments of equal thickness Δr. Let "r" be the radial distance to the middle of the segment in question, and "a" be the area of the developed section $A - A$. The greater the number of segments "n" the more accurate will be the value of volume or WR^2 obtained.

$$WR^2 = \rho\, (\Delta r) \sum_{r=r_1}^{r=r_2} a\, r^2 \qquad \text{Volume} = \Delta r \sum_{r=r_1}^{r=r_2} a$$

Note: Because of the weight of the water clinging to the blades the WR^2 of the propeller in operation is greater in effect than that of the dry propeller. The latter is therefore generally increased by 25 percent for compensation.

TYPICAL EXAMPLE

The flywheel shown below is used in a diesel engine installation. It is required to determine effective WR^2 for calculation of one of the natural frequencies of torsional vibration. The anticipated natural frequency of the system is 56.4 vibrations per sec.



Section A-A

Part of Flywheel	Formula	WR^2
(a)	2c	$\dfrac{10\,[(52)^4 - (43)^4]}{10.75} = 955{,}300$
(b)	2b	$\dfrac{2.375\,[(43)^4 - (39)^4]}{39.2} = 67{,}000$
(c)	16a neglecting $\left(\dfrac{W^2 + L^2}{12}\right)$	$-0.250 \times 1.75 \times 2 \times 1.375\,(25)^2 \times 8 = -6{,}000$
		Total For Rim $= 1{,}016{,}300$ lb. in.^{2}
(d)	5b	$6 \times \dfrac{5.25 \times 2.5 \times 11}{4.90}\left[\dfrac{(11)^2}{3} + 8.5\,(8.5 + 11) + \dfrac{(5.25)^2}{16}\right] = 36{,}300$
(e)	2b	$\dfrac{2.625\,[(17)^4 - (13)^4]}{39.2} = 3{,}700$
(f)	19	$\dfrac{\pi \times 0.250 \times 12}{32}\,[1.697 \times (13)^4 - (6)^4] = 13{,}900$
		Total for remainder of flywheel $= 54{,}100$ lb. in.^{2}

From formula 26

$$C = \frac{6 \times (5.25)^3 \times 2.5 \times 19.5 \times 10^6}{0.1132 \times (11)^2}\left(\frac{11}{3 \times 19.5} + \frac{19.5}{11} - 1\right)$$

$$= 2970 \times 10^6 \ \frac{\text{lb. in.}}{\text{radians}}$$

and $$WR^2 = \frac{1{,}016{,}300}{1 - \dfrac{1{,}016{,}300 \times (56.4)^2}{9.775 \times 2970 \times 10^6}} + 54{,}100 = \underline{1{,}197{,}000 \text{ lb. in.}^2}$$

Note: Since the beads at the ends of the spokes comprise but a small part of the flywheel WR^2 very little error will result in assuming them to be of rectangular cross-section. Also, because of the effect of the clamping bolts, the outer hub will be considered a square equal to the diameter. The spokes will be assumed straight and of midpoint cross-section.